Dickinson Creek Watershed Hydrologic Study

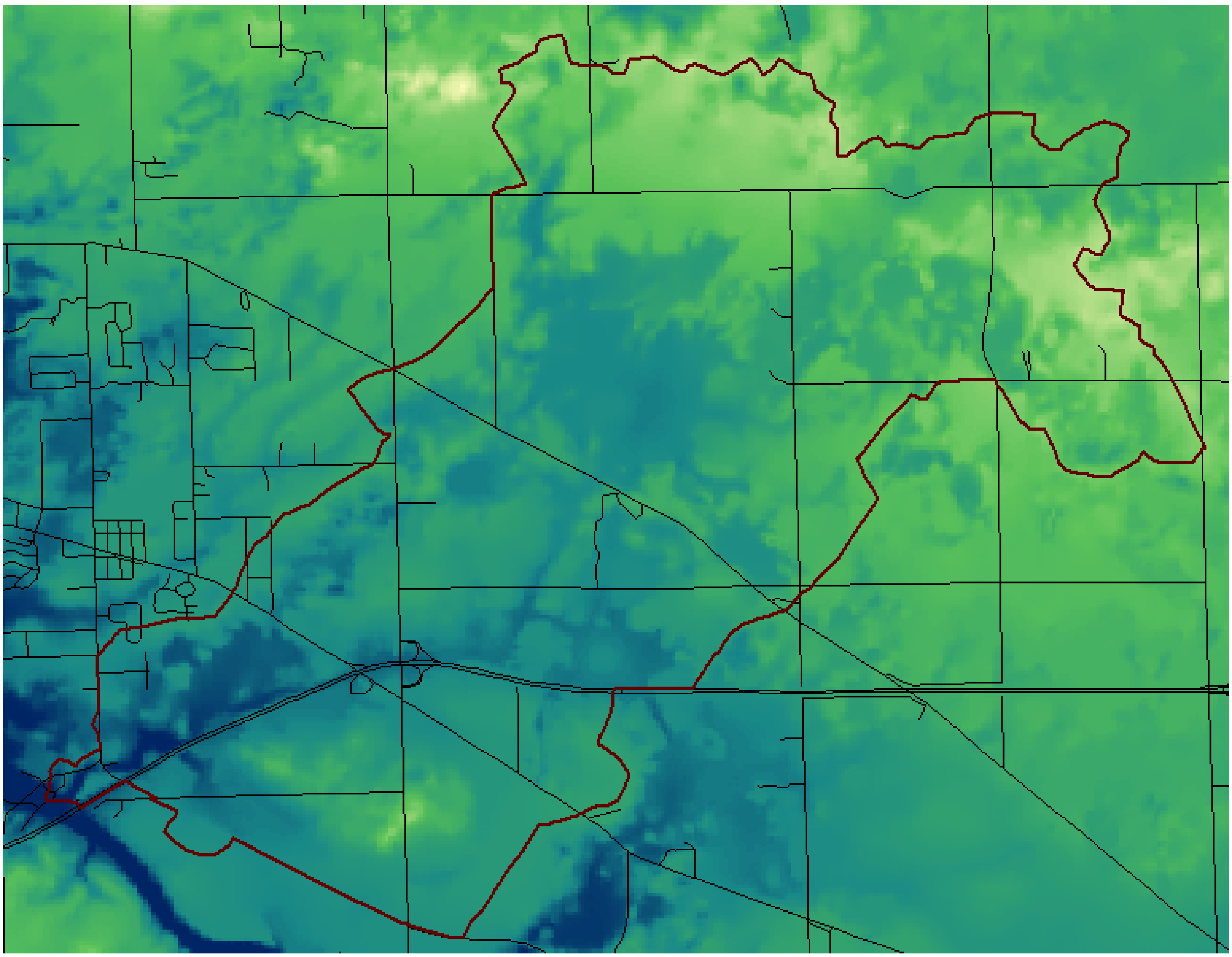

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Table of Contents

This Nonpoint Source (NPS) Pollution Control project has been funded wholly by the United States Environmental Protection Agency (EPA) through a Part 319 grant to the Michigan Department of Environmental Quality. This study is in support of a NPS Kalamazoo River watershed planning grant, 2006-0148. The contents of the document do not necessarily reflect the views and policies of the EPA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

The cover depicts the ground elevations of the Dickinson Creek Watershed. Lighter colors are higher elevations.

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Summary

This hydrologic study of the Dickinson Creek watershed was conducted by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) to help watershed planners and stakeholders better understand the watershed's hydrologic characteristics and the effect of continuing land use transitions in the watershed. The project supports the NPS Kalamazoo River watershed planning grant to the Kalamazoo River Watershed Council.

Hydrologic characteristics of the watershed were evaluated to provide a basis for stormwater management to protect streams from increased erosion and flooding and to help determine the watershed management plan's critical areas. Local governments within the watershed could use the information to help develop stormwater ordinances. Watershed stakeholders may combine this information with other determinants, such as open space preservation, to decide which locations are the most appropriate for wetland restoration, stormwater infiltration or detention, in-stream Best Management Practices (BMPs), or upland BMPs.

Hydrologic modeling is used to quantify changes in stormwater runoff from 1800 through the present and into the future due to land use changes. Agriculture is the dominant land use throughout the watershed. However, urban land uses are increasing, transitioning from agricultural areas, and to a lesser extent, natural areas, particularly in the lower portions of the watershed with ready freeway access.

The watershed study has eight scenarios, Table 1, corresponding to land cover in 1800, 1978, 2005, 2009, and future. General land use trends for the watershed are illustrated in Figure 5. Additional land use information is provided in the Watershed Description section of this report.

Table 1 – Hydrologic Model Scenarios

<table>
<tr><th>Scenario</th><th>Land Cover</th><th>Channel Protection Stormwater Management, New Development</th></tr>
<tr><td>A</td><td>1800</td><td>Not Applicable</td></tr>
<tr><td>B</td><td>1978</td><td>None</td></tr>
<tr><td>C</td><td>2005</td><td>None</td></tr>
<tr><td>D</td><td rowspan="2">2009</td><td>None</td></tr>
<tr><td>E</td><td>Casino site runoff entirely retained</td></tr>
<tr><td>F</td><td rowspan="3">Future</td><td>None</td></tr>
<tr><td>G</td><td>Casino site runoff entirely retained</td></tr>
<tr><td>H</td><td>Casino site runoff entirely retained and 24-hour detention for new development</td></tr>
</table>

Scenarios A, B, and C simulate the actual condition of the watershed at that time. It is our understanding that the casino owners are committed to retaining all stormwater runoff on-site, so Scenario E should simulate the watershed at the completion of casino construction. Scenario D models the watershed if the casino's runoff were uncontrolled; a condition intended only to illustrate the value of the retention by comparison. Scenarios F, G, and H extend the uncontrolled or wise stormwater management choices into the future for additional development that is expected to be generated by the casino.

Water quality, preventing stream channel erosion, and flood control are concerns of watershed planners and stakeholders. The rain events that produce these concerns overlap, Figure 1. In general, small storms, and runoff from the early part of larger storms, are the focus of water quality BMPs. Channel protection measures focus on larger, but still fairly common storm flows. Flood control is generally associated with infrequent events.

This study focuses on channel protection. For that purpose, the 50 percent chance (2-year) 24-hour storm is used in the hydrologic modeling. The hydrologic analysis indicates channel-forming peak flows have been declining, but may increase in the future due to urbanization and the associated imperviousness. Morphologic analysis of the stream at Michigan Avenue indicates moderate to high bank erosion potential and that the stream's power exceeds the resistance of most of the channel bed material, also indicating potential erosion. The stream channel may be adapting to a higher flow regime, or the results may be distorted by excess sand load from construction in the area. Morphologic analysis of the stream ear the mouth indicates low to high bank erosion potential and that stream power approximately equals the resistance of most of the channel bed material, indicating approximate equilibrium. The most actively eroding reach is apparently an isolated problem, but the meander cutoffs that occurred during 2008 illustrate the potential rate of the stream's response to erosive flows.

A river or stream is affected by everything in its watershed. Watershed planning, however, must identify critical areas to focus limited technical and financial resources on the parts of the watershed contributing a disproportionate share of the pollutants. If not properly managed, runoff from future development in the middle and lower watershed has the potential to increase channel-forming peak flows, the duration of channel-forming flows, and the frequency of those flows because the impervious areas may, by themselves, generate higher peak flows than the entire watershed would have previously. Protecting this stream from both higher flows and longer durations of channel-forming flows is important to prevent destabilizing the stream channel. Unless the increased runoff can be mitigated by infiltration or reuse, extended duration of higher flows is likely.

The recently developed *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers* (2008) recommends limiting runoff volume and peak flow to pre-settlement conditions (forest or meadow). Although not explicitly modeled, runoff volume and peak flows as modeled in the 2009 scenario, scenario E, would be the maximum expected runoff in the future if that manual's guidance were followed.

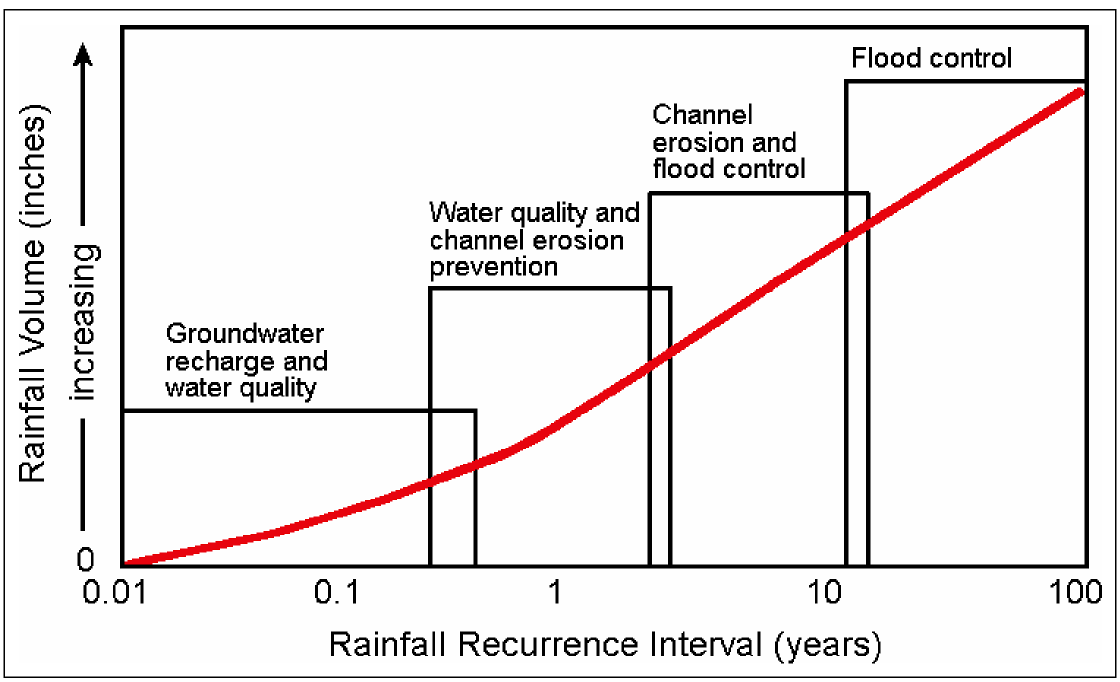


Figure 1 – Rainfall Recurrence and Stormwater Management, adapted from Sullivan, 2002

Watershed Description

Overview

The 11.3 square mile Dickinson Creek watershed, Figure 2, is located in Calhoun County. The creek outlets to the Kalamazoo River near Battle Creek.

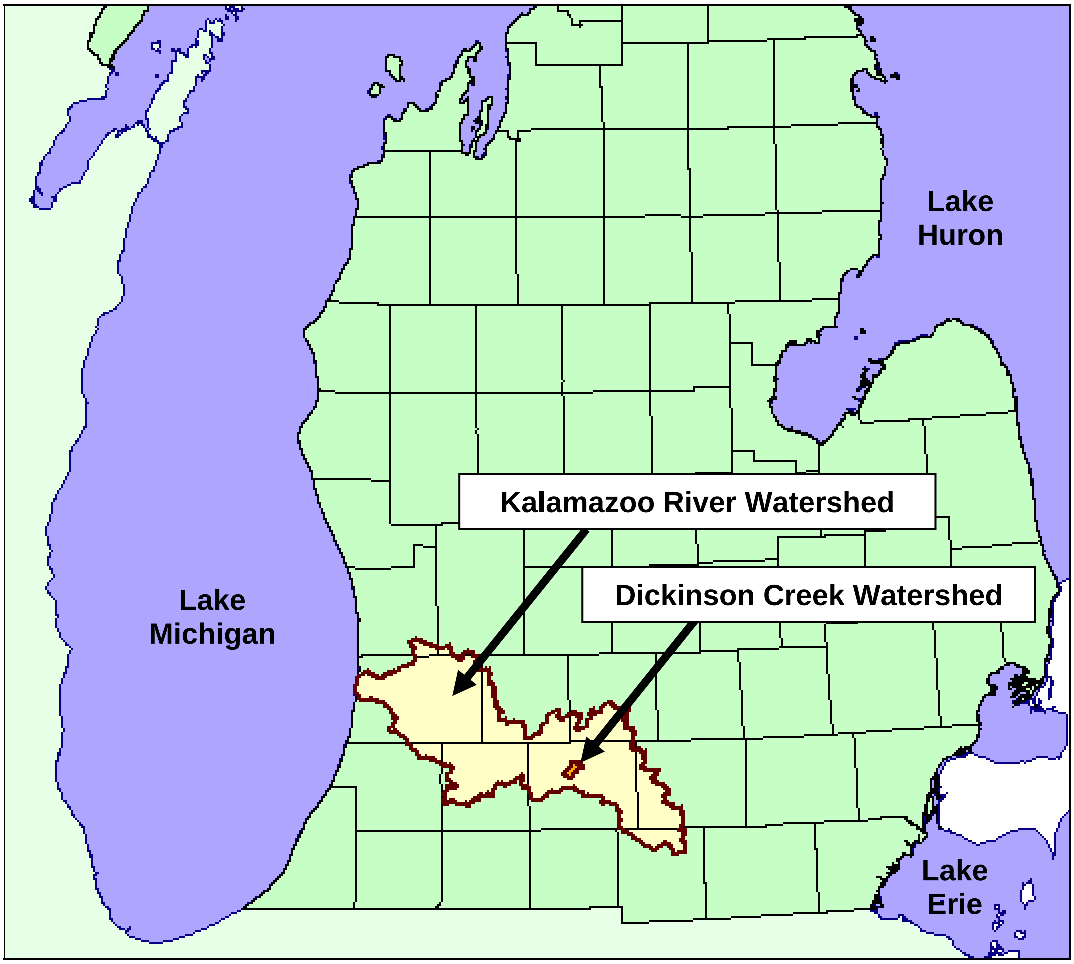


Figure 2 – Dickinson Creek Watershed Location

A stream's ability to move sediment, both size and quantity, is directly related the stream's slope and flow. Thus steeper reaches generally move larger material, such as stones and pebbles, and the flatter reaches tend to accumulate sediment. According to Rosgen, 1996, "generally, channel gradient decreases in a downstream direction with commensurate increases in streamflow and a corresponding decrease in sediment size." A typical river profile is steeper in the headwaters and flatter toward the mouth. The profile of Dickinson Creek, Figure 3, is somewhat different. The steepest reach, based on 10-foot contours, is near the mouth.

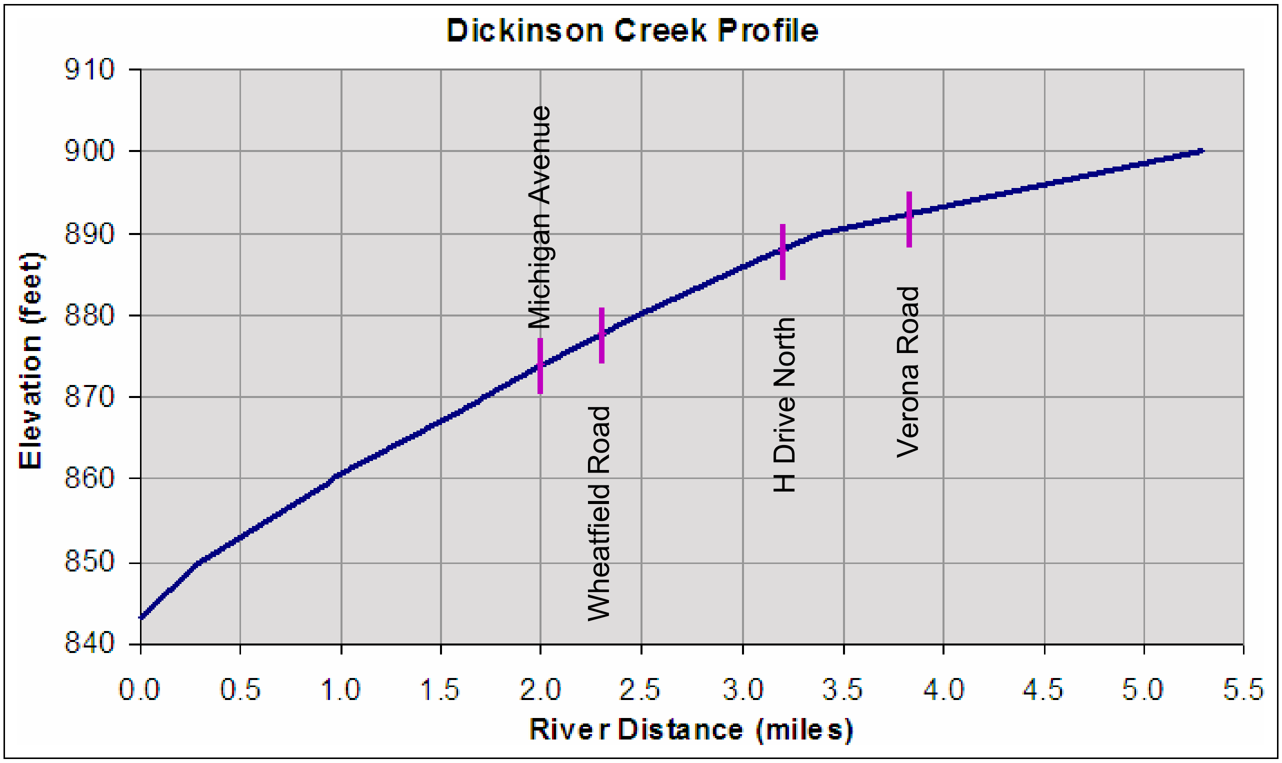


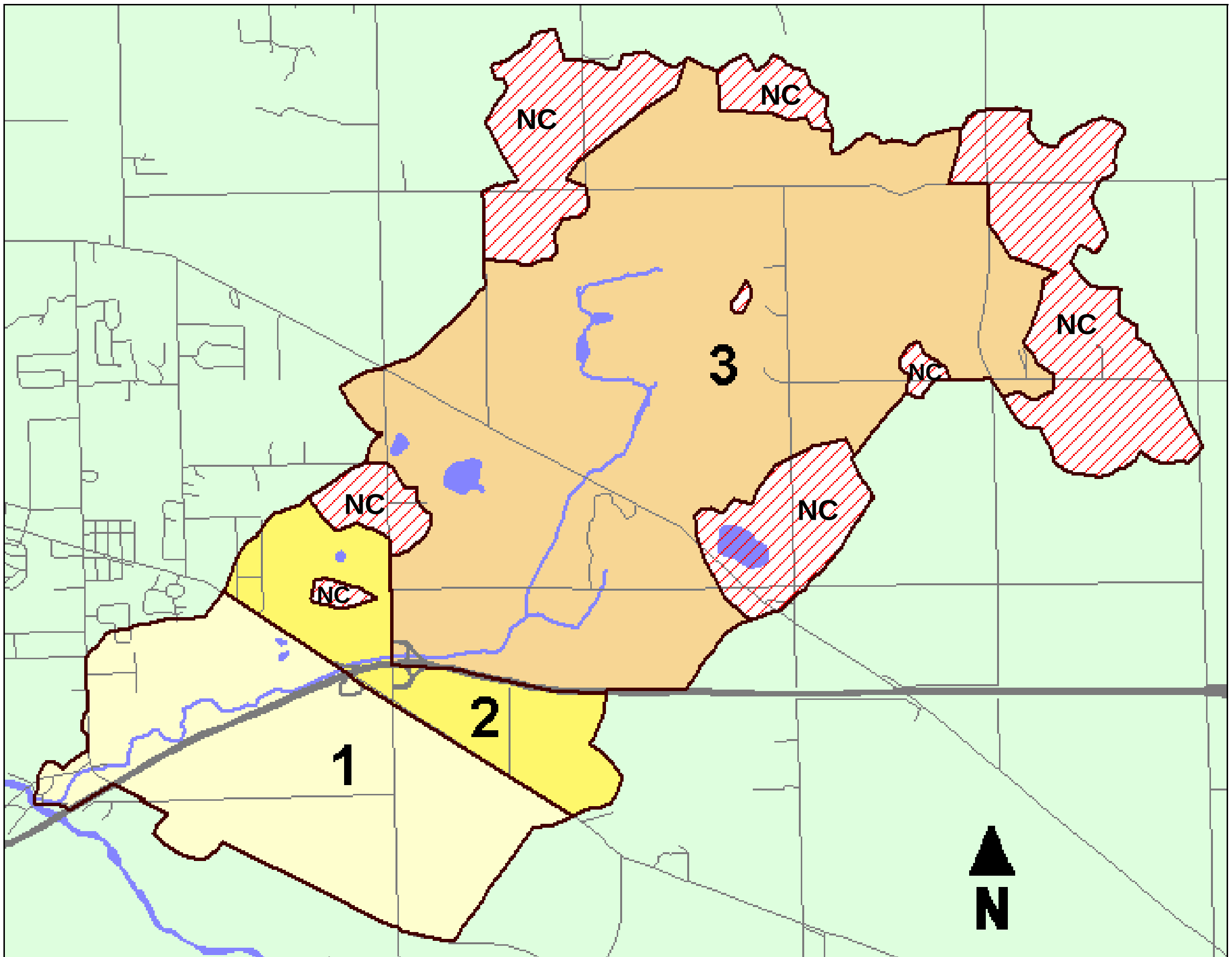
Figure 3: Profile of Dickinson Creek

Trout streams are associated with high quality waters and a good supply of groundwater-fed baseflow, which helps keep the stream flows and temperatures steady. Approximately 21 percent of the Kalamazoo River and its tributaries are designated trout streams. However, Dickinson Creek and its tributaries are not designated trout streams.

Subbasins

This study divides the watershed into 3 subbasins, Figure 4. The subbasins were delineated by HSU based on United States Geological Survey (USGS) quadrangles. Some areas have been identified as non-contributing, meaning that they do not have an apparent overland outlet for surface runoff. We have assumed that these areas, totaling 2.4 square miles, do not contribute surface runoff to Dickinson Creek or its tributaries. Runoff may pool within the area, but that runoff has no natural outlet and therefore must either evaporate or infiltrate. If these areas become developed, artificial drainage may be installed, potentially increasing runoff to Dickinson Creek. Runoff from the non-contributing areas has not been included in any scenario in the Dickinson Creek hydrologic model.

Surface runoff volumes and flows were modeled using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) version 3.2 and the runoff curve number technique. This technique, developed by the Natural Resources Conservation Service (NRCS) in 1954, represents the runoff characteristics from the combination of land use and soil data as a runoff curve number. The technique, as adapted for Michigan, is described in "Computing Flood Discharges For Small Ungaged Watersheds (Sorrell, 2008).



1	Dickinson Creek from the mouth to Michigan Avenue	2.2 sq. mi.
2	Dickinson Creek from Michigan Avenue to Wheatfield Road	0.9 sq. mi.
3	Dickinson Creek above Wheatfield Road	5.8 sq. mi.
NC	Non-Contributing	2.4 sq. mi.

Figure 4 – Dickinson Creek Subbasin Identification

Land Use

General land use trends for the watershed are illustrated in Figure 5. More detailed information for each subbasin is tabulated in Table 2. Land use maps are shown in Figures 6 through 10.

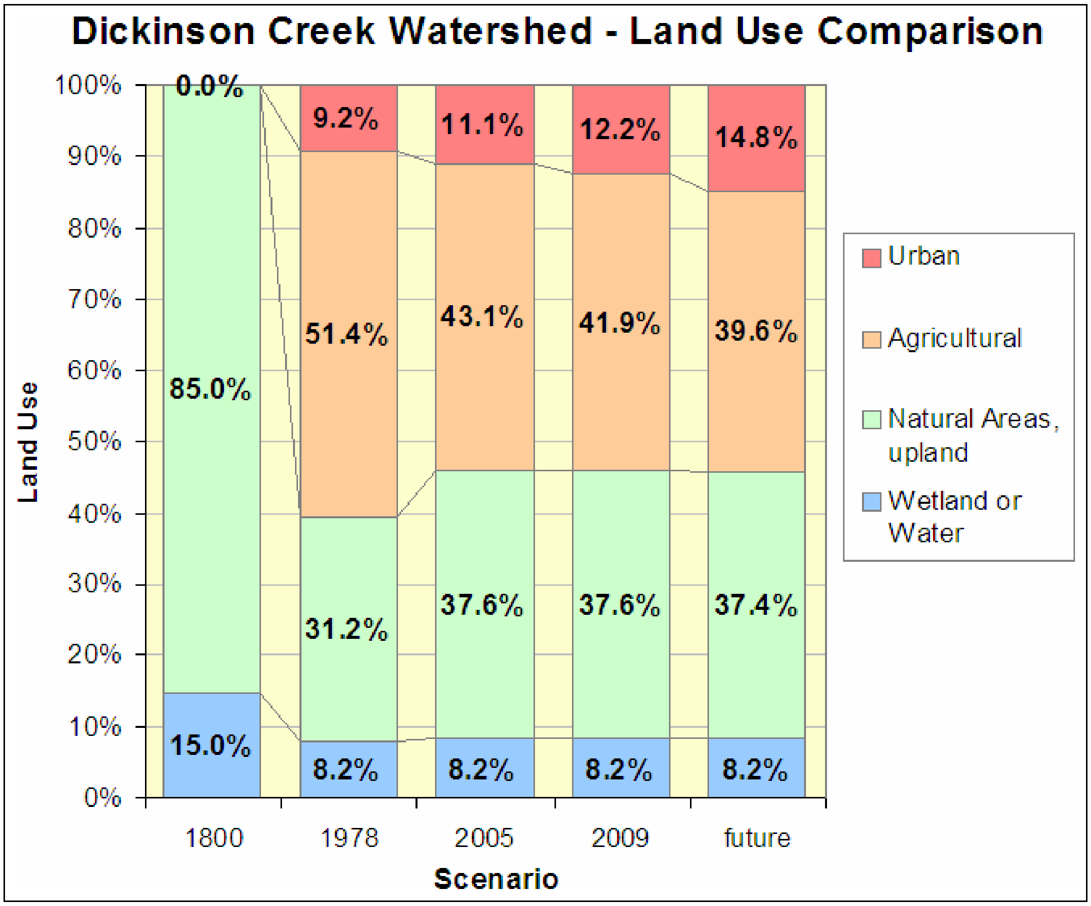


Figure 5 – Land Use Comparison, Dickinson Creek Watershed

Land use circa 1800, Figure 6, is from a statewide Geographic Information System (GIS) database based on original surveyors' tree data and descriptions of the vegetation and land between 1816 and 1856. Michigan was systematically surveyed during that time by the General Land Office, which had been established by the federal government in 1785. The detailed notes taken by the land surveyors have proven to be a useful source of information on Michigan's landscape as it appeared prior to widespread European settlement. The database creators recognize that there are errors in the database due to interpretation and data input.

Land use for 1978, Figure 7, represents a compilation of data from county and regional planning commissions or their subcontractors. This data set is intended for general planning purposes. It is not intended for site specific use. Data editing, manipulation, and evaluation was completed by the Michigan State University Center for Remote Sensing and GIS and by the Michigan Department of Natural Resources (MDNR). Files have been checked by MDNR against original MDNR digital files for errant land cover classification codes.

Land use for 2005, Figure 8, is an update of the 1978 data based on HSU's analysis of 2005 aerial photos. Land use for 2009, Figure 9, is an update of the 2005 data to include the casino. Future land use, Figure 10, revises to 2005 data to include anticipated development sparked by the casino.

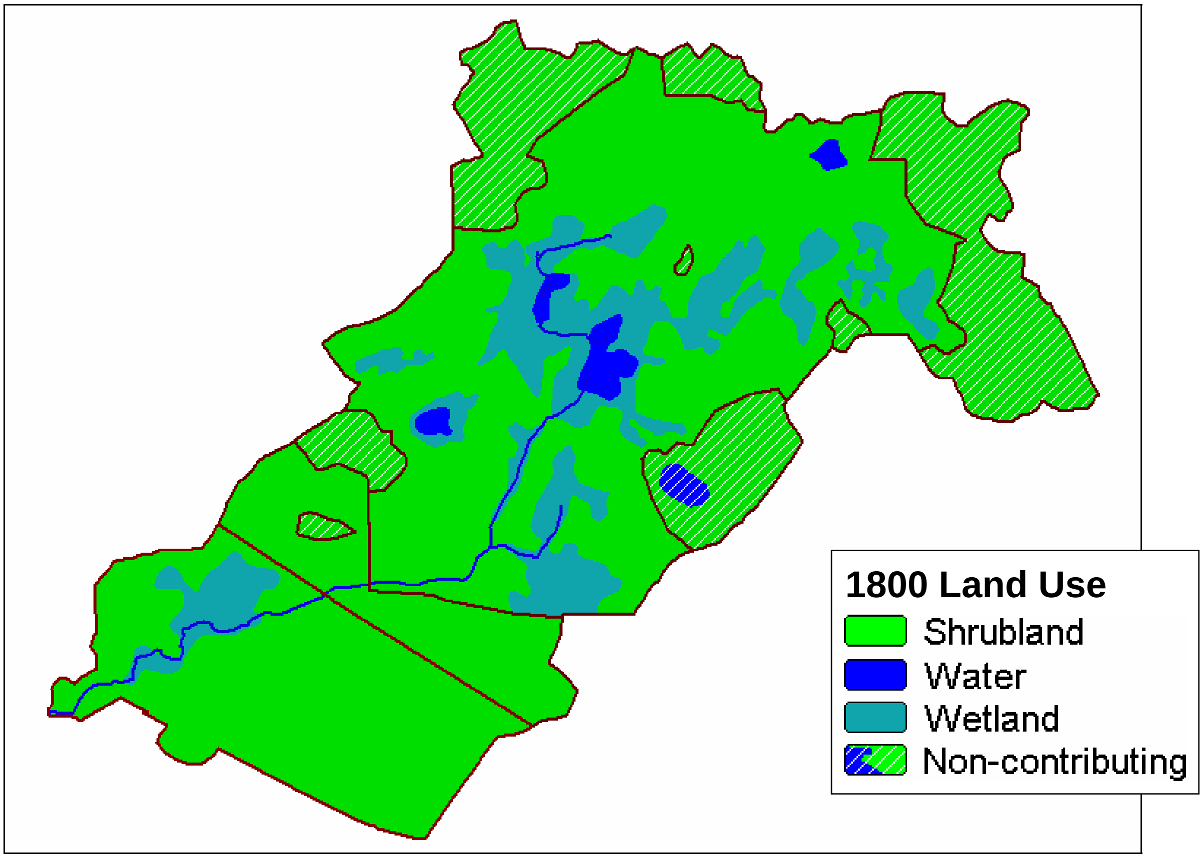


Figure 6 – 1800 Land Cover

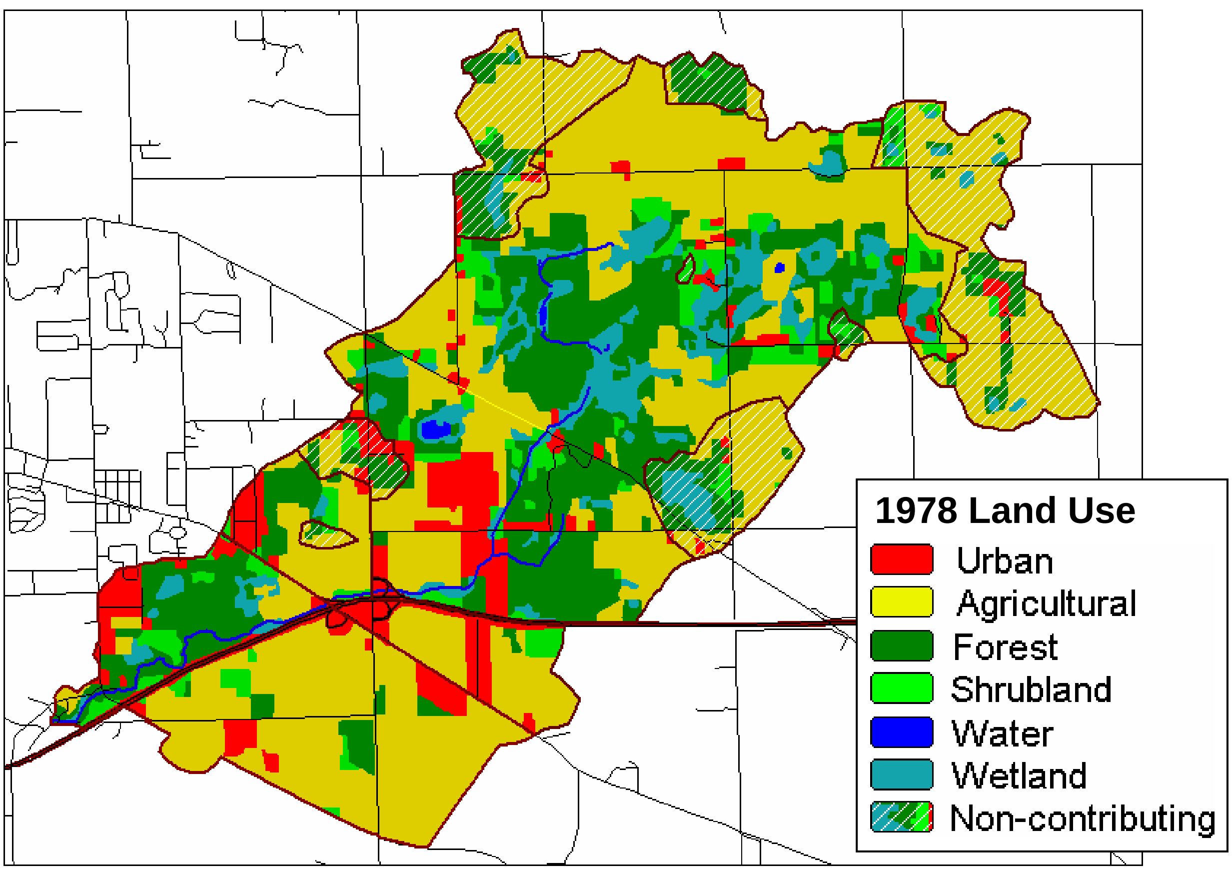


Figure 7 – 1978 Land Cover

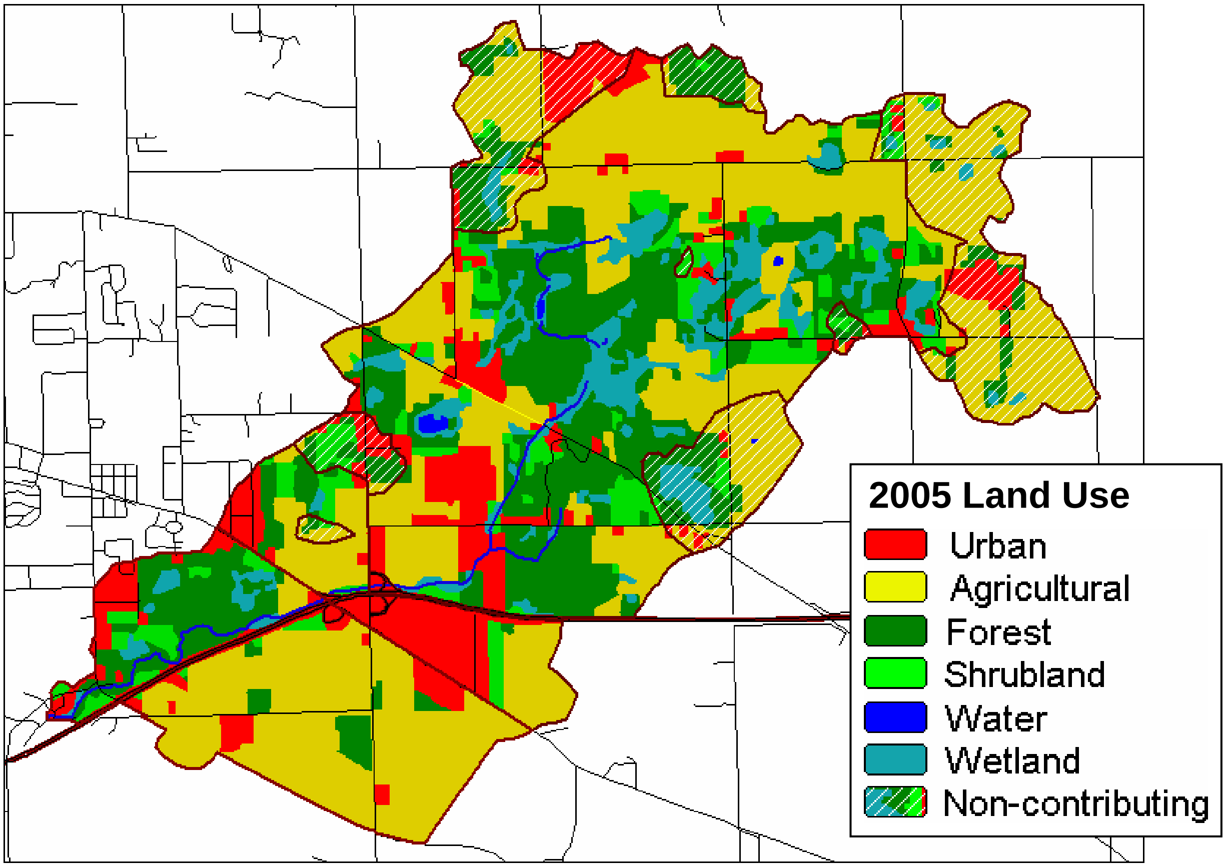


Figure 8 – 2005 Land Cover

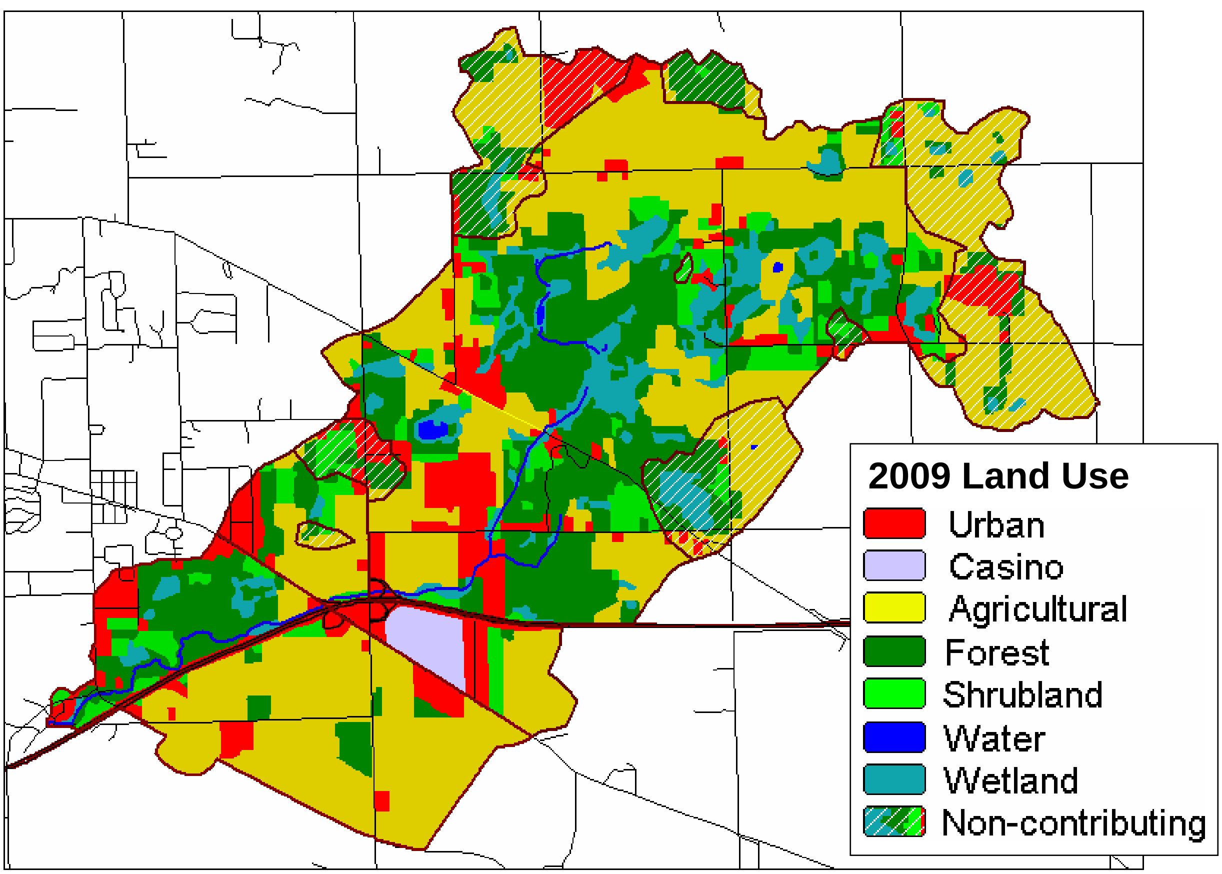


Figure 9 – 2009 Land Cover

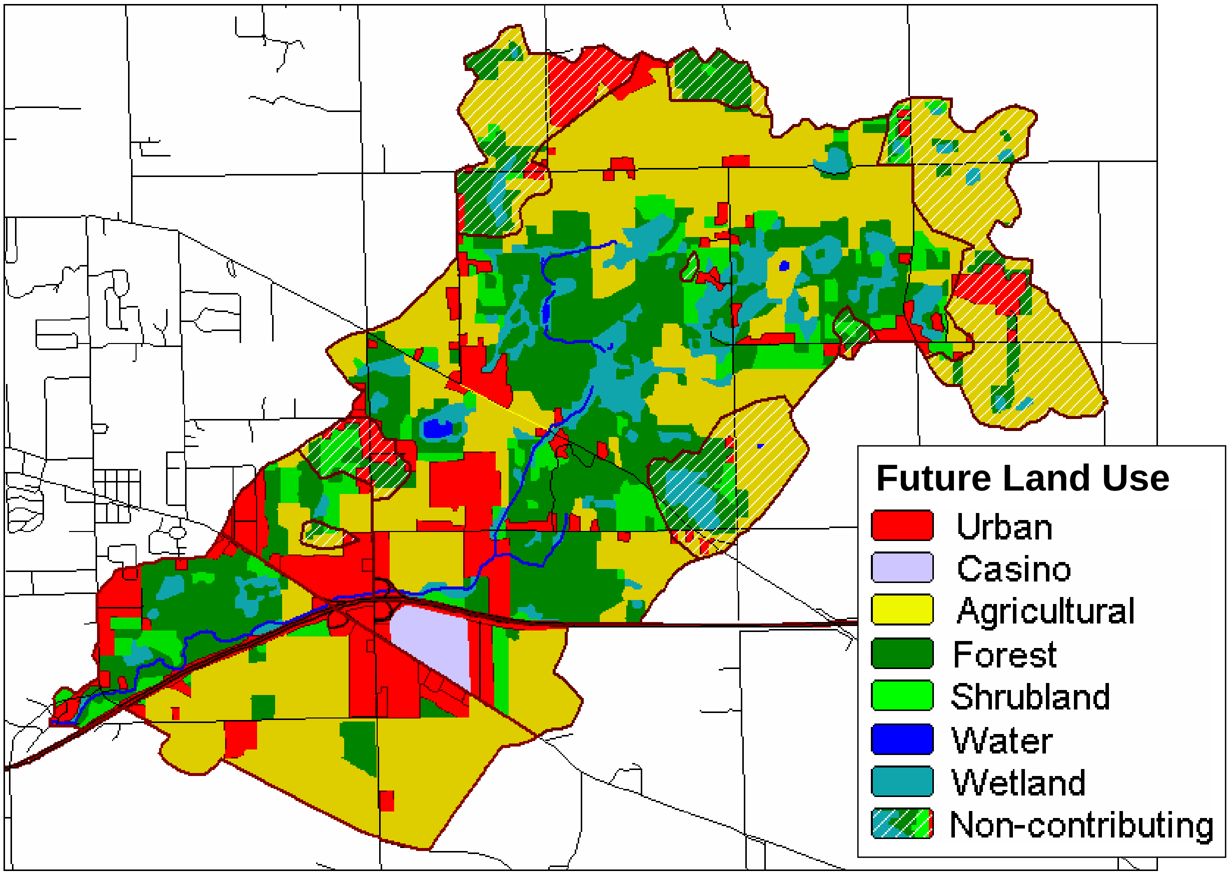


Figure 10 – Future Land Cover

Table 2 – Land Use

Subbasin	Scenario	Residential	Commercial	Industrial	Roads	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland
1	1800									90.5%			9.5%
	1978	5.2%	2.2%	0.7%	4.7%	0.1%	59.4%		0.8%	5.0%	18.8%		3.1%
	2005	5.8%	2.2%	0.8%	4.7%	0.7%	57.0%		0.8%	5.0%	19.8%		3.1%
	2009	5.8%	2.2%	0.8%	4.7%	0.7%	57.0%		0.8%	5.0%	19.8%		3.1%
	Future	5.8%	9.2%	0.8%	4.7%	0.7%	50.4%		0.8%	5.0%	19.4%		3.1%
2	1800									100.0%			
	1978	14.7%	1.6%	0.8%	6.7%		56.4%			7.1%	11.9%		0.8%
	2005	14.6%	3.4%		6.7%		53.8%		1.1%	10.6%	9.1%		0.8%
	2009	14.6%	17.4%		6.7%		39.8%		1.1%	10.6%	9.1%		0.8%
	Future	14.6%	30.6%		6.7%		27.7%		1.1%	9.4%	9.1%		0.8%
3	1800									75.3%		2.6%	22.1%
	1978	3.4%	0.3%		0.4%	3.6%	42.7%	0.4%		6.9%	29.9%	0.3%	12.1%
	2005	5.5%	0.4%		0.4%	3.7%	32.8%	0.4%		7.8%	36.5%	0.3%	12.1%
	2009	5.5%	0.4%		0.4%	3.7%	32.8%	0.4%		7.8%	36.5%	0.3%	12.1%
	Future	5.5%	0.4%		0.4%	3.7%	32.8%	0.4%		7.8%	36.5%	0.3%	12.1%
NC	1800									98.2%		1.8%	
	1978	3.5%					61.1%		0.9%	4.6%	24.7%		5.2%
	2005	4.8%					48.0%		1.2%	5.7%	34.9%		5.4%
	2009	4.8%					48.0%		1.2%	5.7%	34.9%		5.4%
	Future	4.8%	0.2%				47.8%		1.2%	5.7%	34.9%		5.4%
Entire Watershed	1800									85.0%		1.7%	13.3%
	1978	4.7%	0.7%	0.2%	1.7%	1.9%	50.9%	0.2%	0.3%	6.1%	25.1%	0.2%	8.0%
	2005	6.2%	0.9%	0.2%	1.7%	2.0%	42.4%	0.2%	0.5%	7.0%	30.5%	0.2%	8.1%
	2009	6.2%	2.1%	0.2%	1.7%	2.0%	41.3%	0.2%	0.5%	7.0%	30.5%	0.2%	8.1%
	Future	6.2%	4.6%	0.2%	1.7%	2.0%	38.9%	0.2%	0.5%	7.0%	30.5%	0.2%	8.1%

Imperviousness

Percent imperviousness can be compared to the Center for Watershed Protection's Impervious Cover Model (ICM) for headwater urban streams, excerpted in Table 3 and detailed in *The Importance of Imperviousness, The Practice of Watershed Protection* (Schueler and Holland, 2000). Three refinements to the ICM were presented at the 2nd Symposium on Urbanization and Stream Ecology (www.rivercenter.uga.edu/research/urban/urban_meeting3.htm) by Tom Schueler, Chesapeake Stormwater Network, and Lisa Fraley-McNeal, Center for Watershed Protection in May 2008. Figure 11 shows the revised figure, adapted with permission. The three refinements as described by Fraley-McNeal (2008) are:

1. The imperviousness/stream quality relationship is now a cone rather than a line. The cone represents the observed variability in stream quality and also the typical range in expected improvement that could be attributed to subwatershed treatment. The cone illustrates that most regions show a generally continuous but variable gradient of stream degradation as impervious cover increases.

2. The cone width is greatest for impervious cover values less than 10 percent, which reflects the wide variability in stream quality observed for these streams. This prevents the misperception that streams with low impervious cover will automatically possess good or excellent quality. The expected quality of streams in this range of impervious cover is generally influenced more by other watershed characteristics such as forest cover, road density, riparian continuity, and cropping practices.

3. The transition between stream quality classifications is now a band rather than a line. If specific values are used to separate stream categories, the values should be based on actual monitoring data for the ecoregion, the stream indicators of greatest concern, and the predominant predevelopment regional land cover (e.g., crops or forest).

To properly apply and interpret the ICM in a watershed context:

- Watershed scale matters. The use of the ICM should generally be restricted to first to third order alluvial streams.
- The ICM may not work well in subwatersheds with major pollutant point sources, or extensive impoundments or dams within the stream network.
- The ICM is best applied to subwatersheds located within the same physiographic region. In particular, stream slopes, as measured from the top to the bottom of subwatersheds, should be in the same general range.
- The ICM is unreliable when management practices are poor, particularly when impervious cover levels are low (e.g., deforestation, acid mine drainage, intensive row crops, denudation of riparian cover).

When these caveats are applied, the available science generally reinforces the validity of the ICM as a watershed planning tool to forecast the general response of freshwater and tidal streams as a result of future land development.

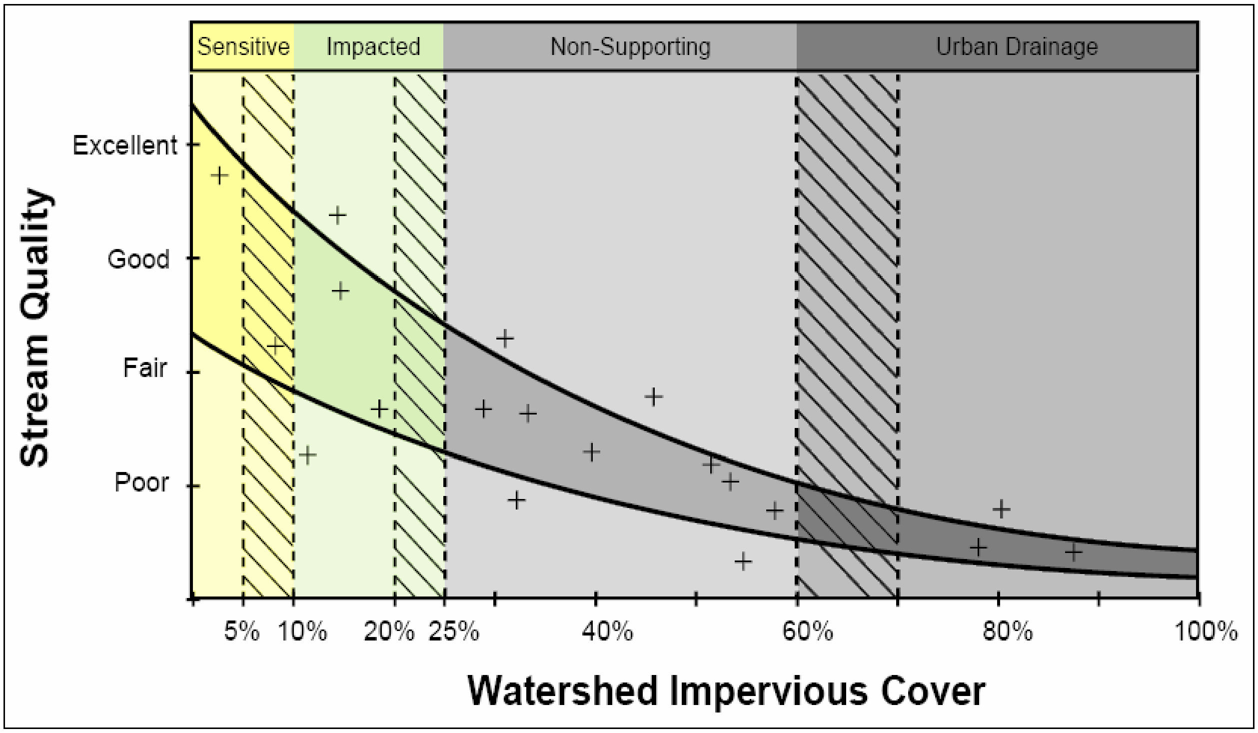


Figure 11 – Impervious Cover Model, adapted with permission (Fraley-McNeal 2008)

Table 3 – Classification of Urban Headwater Streams

Urban Stream Classification	Sensitive	Impacted	Non-supporting
Channel Stability	Stable	Unstable	Highly unstable
Water Quality	Good	Fair	Fair-Poor
Stream Biodiversity	Good-Excellent	Fair-Good	Poor
Resource Objective	Protect biodiversity and channel stability	Maintain critical elements of stream quality	Minimize downstream pollutant loads

Excerpted from “The Practice of Watershed Protection” by Thomas Schueler and Heather Holland, p. 15

The percent imperviousness of each subbasin was analyzed based on land use data, Figures 7 through 10. The percent imperviousness was computed according to Table 4. The imperviousness values for residential, commercial, and industrial are from the Natural Resources Conservation Service (NRCS, 1986).

The results, shown in Figure 12 and tabulated in Table 5, indicate that the watershed overall is at about 5 percent imperviousness, but could approach 10 percent with anticipated development. This places it in the transition zone from sensitive to impacted. The headwater subbasin, subbasin 3, is well below 5 percent imperviousness and is not expected to increase significantly. The expected quality of Dickinson Creek above Wheatfield Road is therefore influenced more by other watershed characteristics such as forest cover, road density, riparian continuity, and cropping practices. Below Wheatfield Road, the impervious areas impact water quality and stream flow. With proper planning and BMP selection, the negative impacts associated with the increased imperviousness can be mitigated.

Table 4 – Imperviousness Table for Impervious Area Analysis

GIS Class	Description	Imperviousness (percent)
1	Residential	38*
2	Commercial	85
3	Industrial	72
4	Road, Utilities	95
5	Gravel Pits	0
6	Outdoor Recreation	0
7	Cropland	0
8	Orchard	0
9	Pasture	0
10	Openland	0
11	Forests	0
12	Open Water	0
13	Wetland	0

* assumed population density of 250 to 1,000 people per square mile

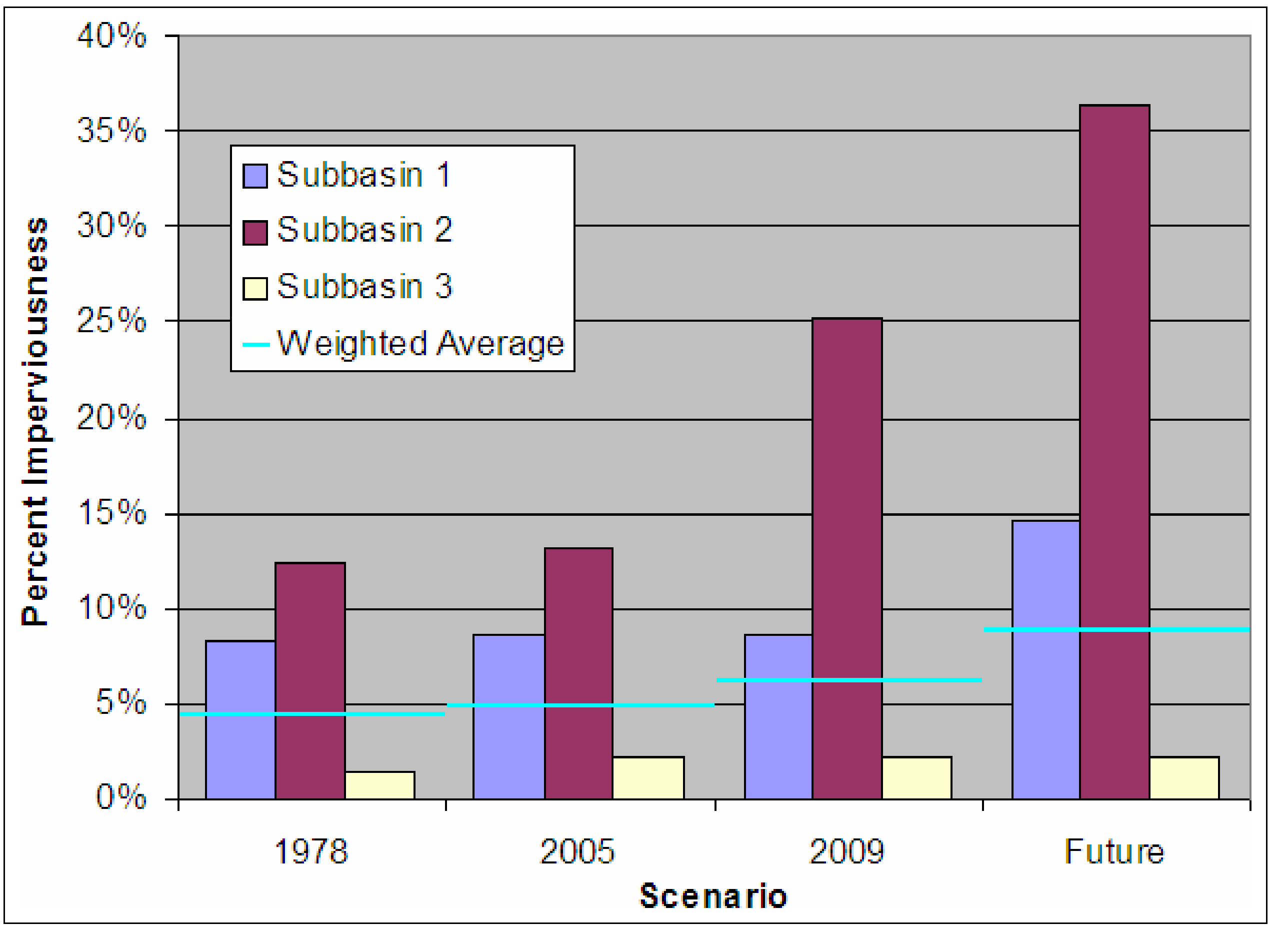


Figure 12 – Percent Imperviousness

Table 5 – Percent Imperviousness

ID	Subbasin	Drainage Area (sq. mi.)	Percent Imperviousness			
			1978	2005	2009	Future
1	Dickinson Creek from the mouth to Michigan Avenue	2.2	8.4%	8.6%	8.6%	14.6%
2	Dickinson Creek from Michigan Avenue to Wheatfield Road	0.9	12.3%	13.2%	25.2%	36.4%
3	Dickinson Creek above Wheatfield Road	5.8	1.4%	2.2%	2.2%	2.2%
	Weighted Average	8.9	4.3%	4.9%	6.1%	8.8%

Soils

Hydrologic soil groups, or hydrogroups, are grouped according to the infiltration of water when the soils are thoroughly wet and receive precipitation from long-duration storms, as described in Table 6. The soils map is shown in Figure 13.

Where the soil is given a dual hydrogroup classification, A/D for example, the soil type selected for the curve number calculation is based on land use. In these cases, the soil type is specified as D for natural land uses, or the alternate classification (A, B, or C) for developed land uses. Soil hydrogroups for each subbasin and the entire watershed, resolved for land use, are shown in Table 7. Changes in hydrogroups with changing land use are minimal in this watershed and have little effect on runoff calculations.

Table 6 – Soil Hydrogroups

Hydrologic Soil Group	Infiltration Rate when thoroughly wet	Description
A	High	Sand Gravelly sand
B	Moderate	Moderately fine textured to moderately coarse textured soils
C	Slow	Moderately fine textured to fine textured soils Soils with a soil layer that impedes downward movement of water
D	Very Slow	Clays Soils with a clay layer near the surface Soils with a permanent high water table

Table 7 – Areal Extent of Soil Hydrogroups for Entire Watershed

Subbasin	Scenario	A	B	C	D	Water
1	1800	0.8%	90.6%	0.0%	8.6%	0.0%
	1978	1.2%	90.8%	0.0%	8.1%	0.0%
	2005	0.9%	90.6%	0.0%	8.5%	0.0%
	2009	0.9%	90.6%	0.0%	8.5%	0.0%
	Future	0.9%	90.6%	0.0%	8.5%	0.0%
2	1800	14.9%	81.4%	0.0%	3.7%	0.0%
	1978	15.1%	81.6%	0.0%	3.3%	0.0%
	2005	15.1%	81.7%	0.0%	3.2%	0.0%
	2009	15.1%	81.7%	0.0%	3.2%	0.0%
	Future	15.1%	82.4%	0.0%	2.5%	0.0%
3	1800	13.5%	63.6%	0.4%	20.2%	2.4%
	1978	14.0%	64.0%	0.4%	19.3%	2.4%
	2005	13.8%	63.8%	0.4%	19.7%	2.4%
	2009	13.8%	63.8%	0.4%	19.7%	2.4%
	Future	13.8%	63.8%	0.4%	19.7%	2.4%
NC	1800	17.1%	78.7%	0.0%	2.5%	1.8%
	1978	16.5%	79.2%	0.0%	2.5%	1.8%
	2005	16.5%	79.0%	0.0%	2.6%	1.9%
	2009	16.5%	79.0%	0.0%	2.6%	1.9%
	Future	16.5%	79.0%	0.0%	2.6%	1.9%
Entire Watershed	1800	11.8%	73.5%	0.2%	12.9%	1.6%
	1978	12.0%	73.8%	0.2%	12.3%	1.6%
	2005	11.8%	73.7%	0.2%	12.7%	1.6%
	2009	11.8%	73.7%	0.2%	12.7%	1.6%
	Future	11.8%	73.7%	0.2%	12.6%	1.6%

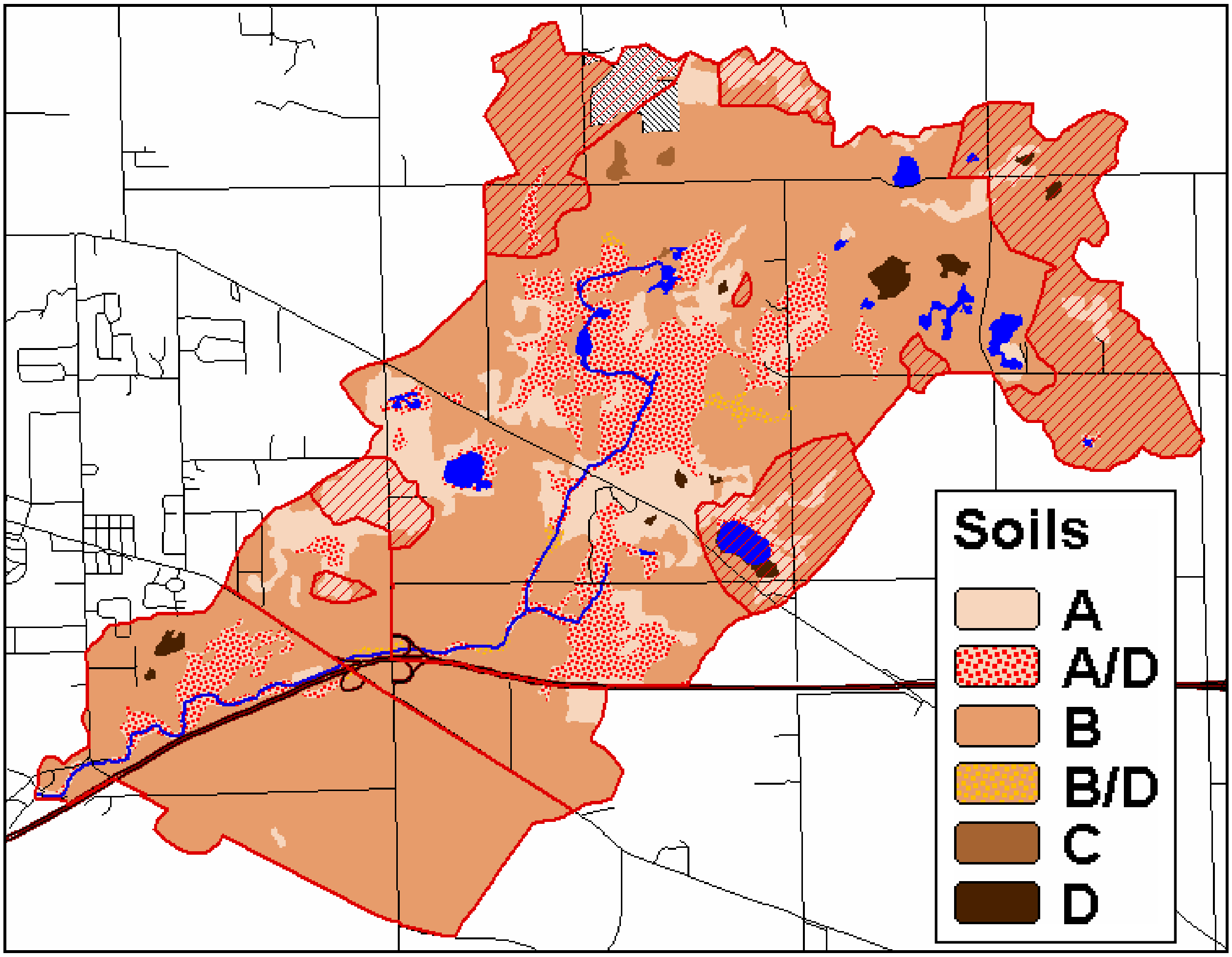
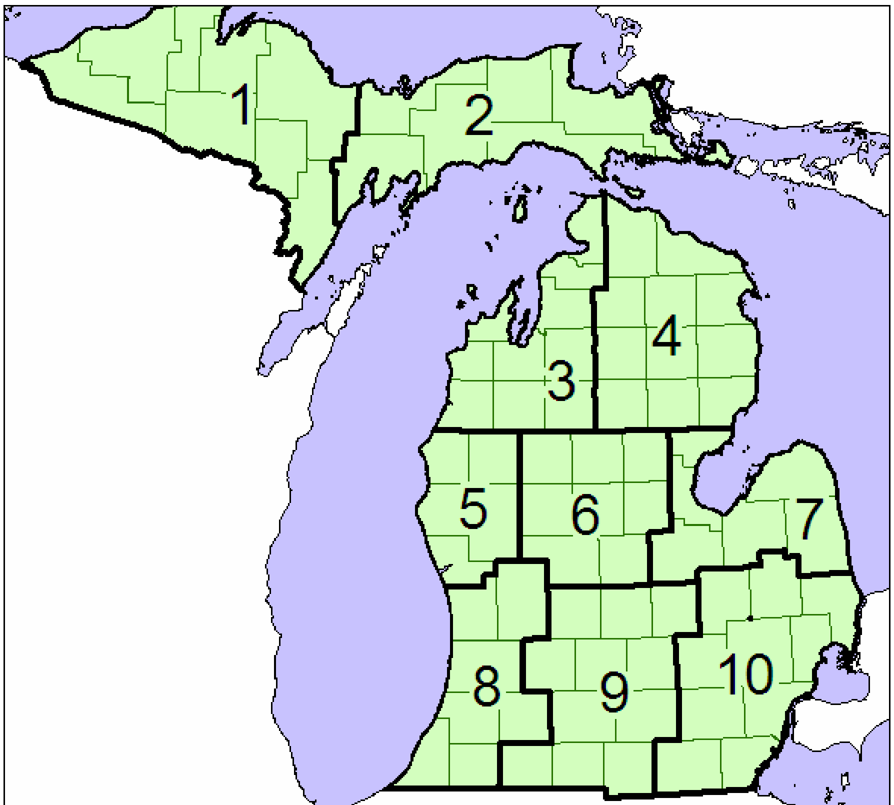


Figure 13 – Soil Hydrogroups

Hydrologic Model Parameters

Rainfall

The design rainfall value used in this study is 2.42 inches, corresponding to the 50 percent chance (2-year) 24-hour storm for the watershed, as tabulated in Rainfall Frequency Atlas of the Midwest, Bulletin 71, Midwestern Climate Center, 1992. This storm was selected because runoff from the 50 percent chance design storm approximates channel-forming flows assuming the watershed is, and was, a storm-driven system. The Dickinson Creek watershed is in climatic zone 9, Figure 14.



Zone	Rainfall frequencies, 24-hour duration (rainfall in inches)					
	2-year	5-year	10-year	25-year	50-year	100-year
1	2.39	3.00	3.48	4.17	4.73	5.32
2	2.09	2.71	3.19	3.87	4.44	5.03
3	2.09	2.70	3.21	3.89	4.47	5.08
4	2.11	2.62	3.04	3.60	4.06	4.53
5	2.28	3.00	3.60	4.48	5.24	6.07
6	2.27	2.85	3.34	4.15	4.84	5.62
7	2.14	2.65	3.05	3.56	3.97	4.40
8	2.37	3.00	3.52	4.45	5.27	6.15
9	2.42	2.98	3.43	4.09	4.63	5.20
10	2.26	2.75	3.13	3.60	3.98	4.36

Figure 14 – Rainfall Amounts for Michigan's Climatic Zones (Dickinson Creek watershed's climatic zone is highlighted)

Runoff Curve Numbers

Calculations

Surface runoff volumes were modeled using the runoff curve number technique developed by the NRCS in 1954. This technique represents the runoff characteristics from the combination of land use and soil data as a runoff curve number. The technique, as adapted for Michigan, is described in "Computing Flood Discharges For Small Ungaged Watersheds" (Sorrell, 2008).

The runoff curve numbers (CN) were calculated using GIS technology from the digital land use and soil data shown in Figures 6 through 10 and 16. Housing density is a part of the curve number calculations. Average residential lot size was specified as 0.50 acres. Runoff curve numbers for each subbasin are listed in Appendix A. Additional details on the GIS method are at www.michigan.gov/deqhydrology, GIS category, Calculating Runoff Curve Numbers with GIS.

The calculated runoff curve numbers for 2005 land cover were calibrated against monitoring data for Dickinson Creek. As a result, directly connected impervious areas (DCIA) for subbasins 1 and 2 were modeled separately from the rest of the subbasins. DCIA for 2005 is based on the model calibration. DCIA for 1978, 2009, and future scenarios are based on the 2005 values and engineering judgment. See Appendix B for model calibration details.

The developed areas that include 24-hour stormwater extended detention in the future scenarios, Figure 15, were modeled as separate elements. An impervious area for each of these developed areas was assigned based on the land use GIS data and Table 4. The pervious portion of the drainage area was assigned a curve number corresponding to open space in good condition for the associated soil type.

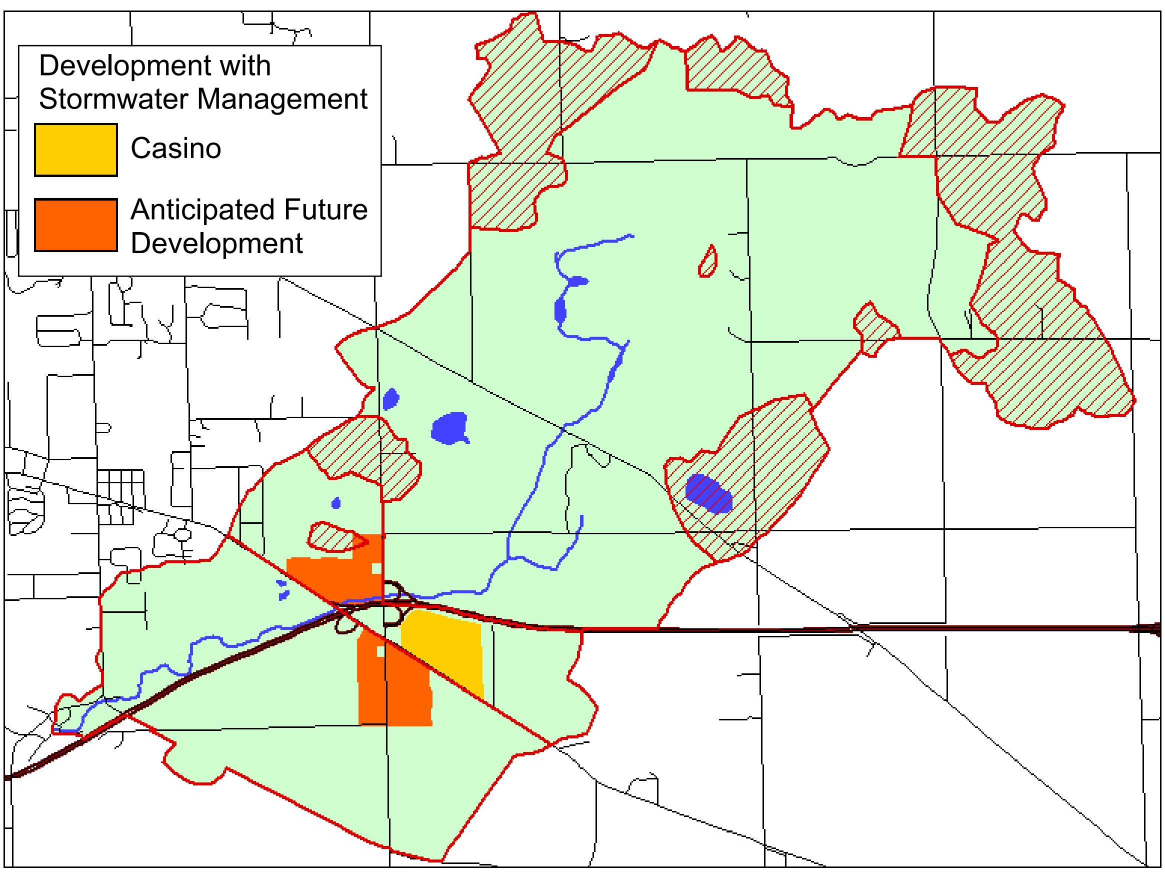


Figure 15: Future Development Modeled with Extended Detention Stormwater Management

Assumptions and Limitations

Antecedent Runoff Condition

The runoff curve numbers are Antecedent Runoff Condition (ARC) II to approximate typical conditions. To accurately model a watershed over time, the curve numbers would vary due to rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature, which are collectively called the Antecedent Runoff Condition. ARC replaces, but is not the same as, Antecedent Moisture Condition (AMC). Chapter 10 of the NEH (2004) now states "No apparent relationship between antecedent precipitation and curve number exists." ARC is divided into three classes. Classes I and III can be considered probability boundaries of the curve number variable. ARC I approximates drier conditions and ARC III wetter conditions.

P/S Test

An assumption of the runoff curve number technique is that the entire watershed contributes runoff. The curve number technique documentation is the NRCS's Part 630 Hydrology National Engineering Handbook. Chapter 10, Section 630-1003 Accuracy, of this handbook states, "The runoff equation generally did reasonably well where the runoff was a substantial fraction of the rainfall, but poorly in cases where the runoff was a small fraction of the rainfall; i.e., the CNs are low or rainfall values are small. Curve numbers were originally developed from annual flood flows from experimental watersheds, and their application to low flows or small flood peak flows is not recommended. (See Hawkins, et al. 1985, for a precise measure of small.)" According to Hawkins, "relative storm size is then proposed to be defined on the ratio P/S, where a "large" storm has P/S>0.46, when 90 percent of all rainstorms will create runoff." P/S is the ratio of precipitation, P, to potential maximum retention, S. When P/S is less than 0.46, runoff volumes and peak flows for smaller events would depend upon the portion of each subbasin contributing runoff, which will vary with the rainfall total and intensity.

None of the curve numbers for the 1800 land use scenario meet the P/S test, Table 8, meaning only a portion of a subbasin may be contributing runoff, not the entire subbasin, as assumed in the model. Peak flow and runoff volume results for those areas may be underestimated.

Table 8 – Model results that do not meet the P/S ≥ 0.46 test

Subbasin		Scenario	CN (ARC II)	P/S
1	Dickinson Creek from the mouth to Michigan Avenue	1800	60.1	0.36
2	Dickinson Creek from Michigan Avenue to Wheatfield Road	1800	54.6	0.29
3	Dickinson Creek above Wheatfield Road	1800	61.3	0.38

Snowmelt

The hydrologic modeling assumes that the Dickinson Creek watershed is more a storm-driven system more than a snowmelt-driven system. In a storm-driven system, rainfalls during the growing season usually generate the flood flows. Snowmelt-driven systems are usually less flashy than storm-driven systems, because the snow pack supplies a steadier rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, can produce dramatic flow increases. The runoff from the rain and snowmelt also likely occur with saturated or frozen soil conditions, when the ground can absorb or store less water, resulting in more overland flow to surface waters than would occur otherwise.

Time of Concentration and Storage Coefficients

Time of concentration, Tc, is the time it takes for water to travel from the hydraulically most distant point in the subbasin to the design point. Times of concentration for each subbasin were calculated using USGS quadrangles following the methodology described in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008). The same time of concentration values were used in all land use scenarios.

Storage coefficients, SC, represent temporary storage in ponds, lakes, or swampy areas in each subbasin. Storage Coefficients are initially set equal to the curve numbers then iteratively adjusted to provide a peak flow reduction equal to the ponding adjustment factors shown in Table 9 and detailed in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008).

Table 9 – Ponding Adjustment Factors

ID	Subbasin	Scenario	Ponding	Adjustment Factor, 50% Storm
1	Dickinson Creek from the mouth to Michigan Avenue	1800	9.5%	0.59
		1978	3.1%	0.70
		2005	3.1%	0.70
		2009	3.1%	0.70
		Future	3.1%	0.70
2	Dickinson Creek from Michigan Avenue to Wheatfield Road	1800	0.0%	1.00
		1978	0.8%	0.85
		2005	0.8%	0.85
		2009	0.8%	0.85
		Future	0.8%	0.85
3	Dickinson Creek above Wheatfield Road	1800	24.7%	0.51
		1978	12.5%	0.57
		2005	12.5%	0.57
		2009	12.5%	0.57
		Future	12.5%	0.57

Results

Hydrologic Analysis

General

The impetus for this study was whether recent or anticipated hydrologic changes adversely affect Dickinson Creek's morphology, the form and structure of its channel. Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. Hydrologic changes that increase runoff volumes and peak flows from equivalent storms increase channel-forming flows, which causes more streambank and bed erosion as the stream enlarges to accommodate the higher flows. This study is therefore focused on model results from the 50 percent chance (2-year), 24-hour design storm. The modeled precipitation event is shown in Figures 19 through 22.

The watershed study has eight scenarios, Table 10, corresponding to land cover in 1800, 1978, 2005, 2009, and anticipated future development. Scenarios A, B, and C simulate the actual condition of the watershed at that time. It is our understanding that the casino owners are committed to retaining all stormwater runoff on-site, so Scenario E is intended to model the condition of the watershed once casino construction is complete. In contrast, Scenario D models the watershed if the casino's runoff were uncontrolled; a condition intended to illustrate the value of the retention. Scenarios F, G, and H extend the stormwater management choices into the future for development that is likely to be generated by the casino. Scenario H assumes runoff from new development will be controlled by extended detention, so that runoff that enters a detention pond is released on average 24 hours later. New development was assumed to not alter the boundary between subbasins. Redevelopment was not considered.

Table 10 – Hydrologic Model Scenarios

<table>
<tr><th>Scenario</th><th>Land Cover</th><th>Channel Protection Stormwater Management, New Development</th></tr>
<tr><td>A</td><td>1800</td><td>Not Applicable</td></tr>
<tr><td>B</td><td>1978</td><td>None</td></tr>
<tr><td>C</td><td>2005</td><td>None</td></tr>
<tr><td>D</td><td rowspan="2">2009</td><td>None</td></tr>
<tr><td>E</td><td>Casino site runoff entirely retained</td></tr>
<tr><td>F</td><td rowspan="3">Future</td><td>None</td></tr>
<tr><td>G</td><td>Casino site runoff entirely retained</td></tr>
<tr><td>H</td><td>Casino site runoff entirely retained and 24-hour detention for new development</td></tr>
</table>

Results –Subbasins

Runoff volumes were calculated for each subbasin for the 50 percent chance (2-year), 24-hour storm. The results are shown in Figure 16 and tabulated in Table 11. Results are provided in both acre-feet (volume) and acre-inches per acre or, more simply, inches (volume per area). The volumes enable comparison of each subbasin's total stormwater contribution. The volumes per area enable comparison of each subbasin's hydrologic responsiveness.

In terms of total volume, the watershed would have generated 116 acre-feet of runoff from a 2.42 inch rainfall in 1800. In 1978, it would have generated 258 acre-feet, an increase of 142 acre-feet, or 122 percent. The increased channel-forming flow runoff volume, and likely peak flow, has undoubtedly resulted in channel enlargement as the Dickinson Creek and its tributaries adapt to the higher flows.

From 1978 to 2005, modeled runoff volume dropped by 14 acre-feet, or 5 percent, due almost entirely to the transition of agricultural land to forest. If the casino currently under construction retains all of its stormwater as expected, total runoff is expected to drop another 5 acre-feet. Without the retention, runoff would have increased by 6 acre-feet. Moving forward, runoff volumes in the modeled scenarios are expected to increase by another 22 acre-feet. If new development includes volume controls, this increase could be reduced or reversed.

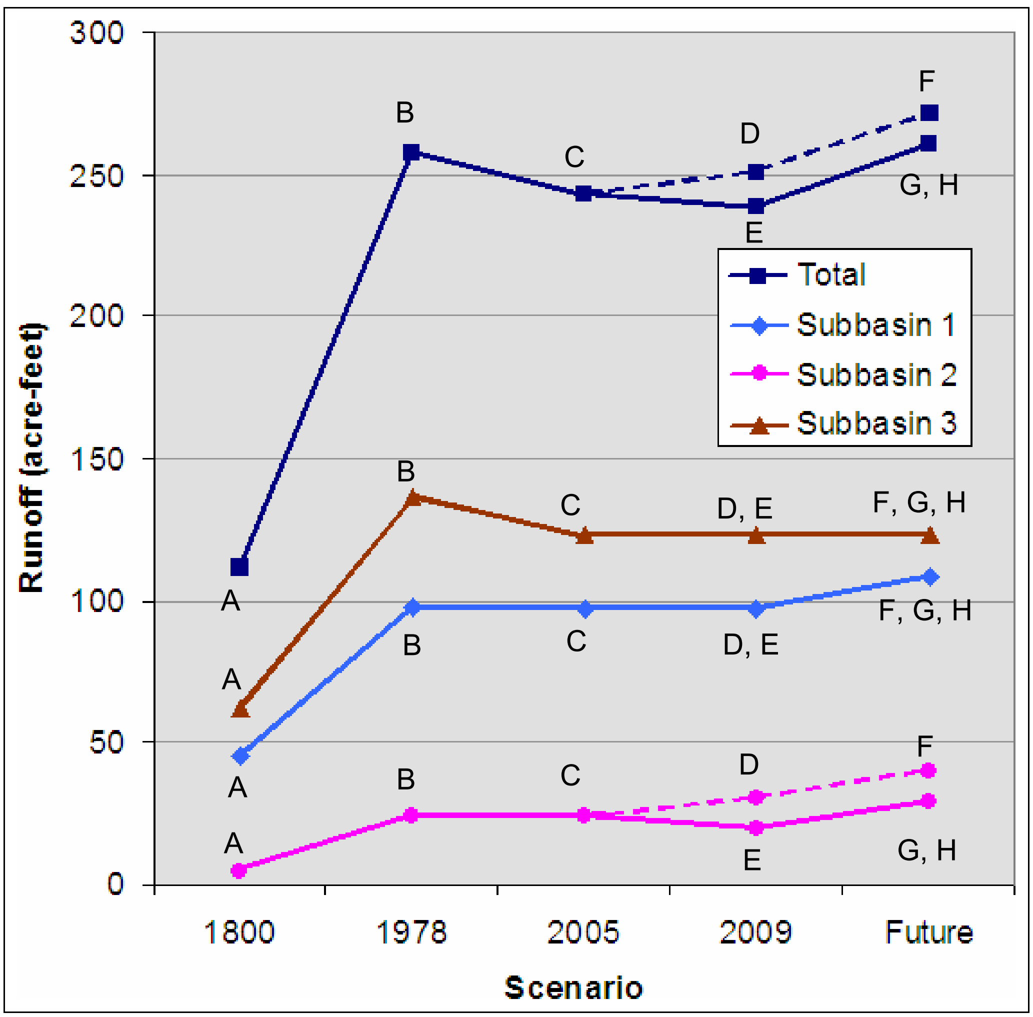


Figure 16 – Runoff Volume by Subbasin

Table 11 – Runoff Volume by Subbasin

Subbasin	Scenario	Drainage Area (sq. mi.)	Surface Runoff (acre-feet)	Surface Runoff/Area (inches)
1. Dickinson Creek at mouth	A. 1800	2.20	45.4	0.39
	B. 1978		97.7	0.83
	C. 2005		97.0	0.83
	D. 2009, no stormwater management		97.0	0.83
	E. 2009, casino retention		97.0	0.83
	F. Future, no stormwater management		109	0.93
	G. Future, casino retention		109	0.93
	H. Future, casino retention, extended detention for new development		109	0.93
2. Dickinson Creek at Michigan Avenue	A. 1800	0.91	4.1	0.09
	B. 1978		24.2	0.50
	C. 2005		23.8	0.49
	D. 2009, no stormwater management		30.6	0.63
	E. 2009, casino retention	0.78	19.4	0.47
	F. Future, no stormwater management	0.91	40.4	0.83
	G. Future, casino retention	0.78	29.2	0.70
	H. Future, casino retention, extended detention for new development	0.78	29.2	0.70
3. Dickinson Creek at Wheatfield Road	A. 1800	5.70	61.9	0.20
	B. 1978		136	0.45
	C. 2005		123	0.40
	D. 2009, no stormwater management		123	0.40
	E. 2009, casino retention		123	0.40
	F. Future, no stormwater management		123	0.40
	G. Future, casino retention		123	0.40
	H. Future, casino retention, extended detention for new development		123	0.40
Totals	A. 1800	8.81	112	0.24
	B. 1978		258	0.55
	C. 2005		244	0.52
	D. 2009, no stormwater management		250	0.53
	E. 2009, casino retention	8.68	239	0.52
	F. Future, no stormwater management	8.81	272	0.58
	G. Future, casino retention	8.68	261	0.56
	H. Future, casino retention, extended detention for new development	8.68	261	0.56

Results – Dickinson Creek

The conveyance of the runoff through the drainage system to the stream determines the stream's flows. Peak flows are determined not only by the volume of runoff, but also the drainage system characteristics – slope, length, hydraulic roughness, and ponding. Relatively frequent flows, flows that recur on average every one to two years, are considered channel-forming flows and have more effect on channel form than extreme flood flows. Increases in runoff from relatively small storms, such as the 50 percent chance (2-year) 24-hour storm correspondingly increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows. For this study, two locations, Dickinson Creek at Michigan Avenue and near the mouth, were analyzed in detail for the 50 percent chance 24-hour design storm.

Peak flow results are shown in Table 12 and Figures 17 and 18 for each scenario. However, for three scenarios the peak flows are caused by the directly connected impervious areas, while for the other five scenarios, the entire watershed is generating the peak flows. For this reason, direct comparison of the peaks is not as useful as comparisons of the hydrographs, Figures 19 through 22. Figures 19 and 20 illustrate the hydrographs for each scenario. For clarity, Figures 21 and 22 exclude the hydrographs for scenarios D and F, which were modeled only to illustrate what could happen if the stormwater from the casino wasn't retained.

Figures 23 and 24 illustrate the effect of extended detention, scenario H, applied to runoff from future development. In scenario H, runoff that is managed with extended detention is released on average 24 hours after it enters the detention pond. Figures 25 and 26 illustrate the in-stream effect of the new development with and without extended detention on Dickinson Creek. In Scenario G (future without extended detention), the stream will see a higher peak shortly after the storm that is caused by the impervious areas, then another smaller peak caused by runoff from the upper watershed and the other portions of the lower watershed. Scenario H (future with extended detention) yields hydrographs that are similar to scenario E (2009) at both locations, but with four to five percent higher peak flows and slightly longer durations of higher flows, all of which is attributable to the increased runoff volume.

A methodology termed the Work Index estimates the erosive effect of flow changes. This enables comparison of the effects shown in Figures 25 and 26 where both the peak flows and the duration of high flows are changing. The Work Index, *W'*, is a measure of the erosive potential of the work done by bank shear stresses integrated over the duration of the flood event. The Work Index equation is

$$W' = \int_{flood} (d - d_c)^e V dt$$

where *d* is the depth of flow, d_c is the critical depth for bed mobility, *V* is the stream velocity, and *e* is an exponent between 1 and 2.5 (MacRae 1992, 1996). For additional information, refer to Appendix E. According to Palhegyi (personal communication, 2008) the generally accepted exponent for this equation is 1, which gives equal weight to the magnitude of flow changes above a critical depth and to changes in the duration of higher flows. The critical depth, d_c, for this study, is 75 percent of bankfull depth, based on a sensitivity analysis performed for the Rabbit River watershed management plan (Hoeksema, personal communication, 2007). Bankfull depth was estimated to be 1.7 feet for both locations. The critical depth for both locations is 1.3 feet, which translates to a flow of 10 cubic feet per second (cfs) at Michigan Avenue and 14 cfs near the mouth.

Work Index trends, not the values, are what matters. Figures 27 and 28 show the results expressed as ratios from the 2005 scenario results. Both locations show declines in erosive potential since 1978, with further declines to 2009 when all of the casino runoff is retained. The future scenarios show nearly identical increases in erosive potential at both locations, regardless of whether the runoff is uncontrolled or detained, because the detained runoff coincides with higher flows from the upper watershed. As the work index ratio increases above 1.0, erosive potential increases relative to the reference condition. These results should be considered specific to this watershed and may not be applicable to other watersheds. For example, our Strawberry Creek hydrologic study (2008) demonstrates that extended detention can delay some of the outflow until in-stream flows have little erosive potential. The erosive potential of the scenarios that assume the casino runoff is not retained further demonstrate the value of runoff volume control.

Runoff increases can impact water quality and flooding, as well as channel erosion. These changes can be moderated with effective stormwater management techniques. Refer to the Stream Morphology and Stormwater Management sections for more detail.

Table 12 – Peak Flow Results

Location	Scenario	Peak Flow (cfs)
Dickinson Creek at Michigan Avenue	A. 1800	18
	B. 1978	60
	C. 2005	48
	D. 2009, no stormwater management	67
	E. 2009, casino retention	47
	F. Future, no stormwater management	112
	G. Future, casino retention	66
	H. Future, casino retention, extended detention for new development	49
Dickinson Creek at mouth	A. 1800	26
	B. 1978	95
	C. 2005	79
	D. 2009, no stormwater management	107
	E. 2009, casino retention	73
	F. Future, no stormwater management	174
	G. Future, casino retention	128
	H. Future, casino retention, extended detention for new development	77

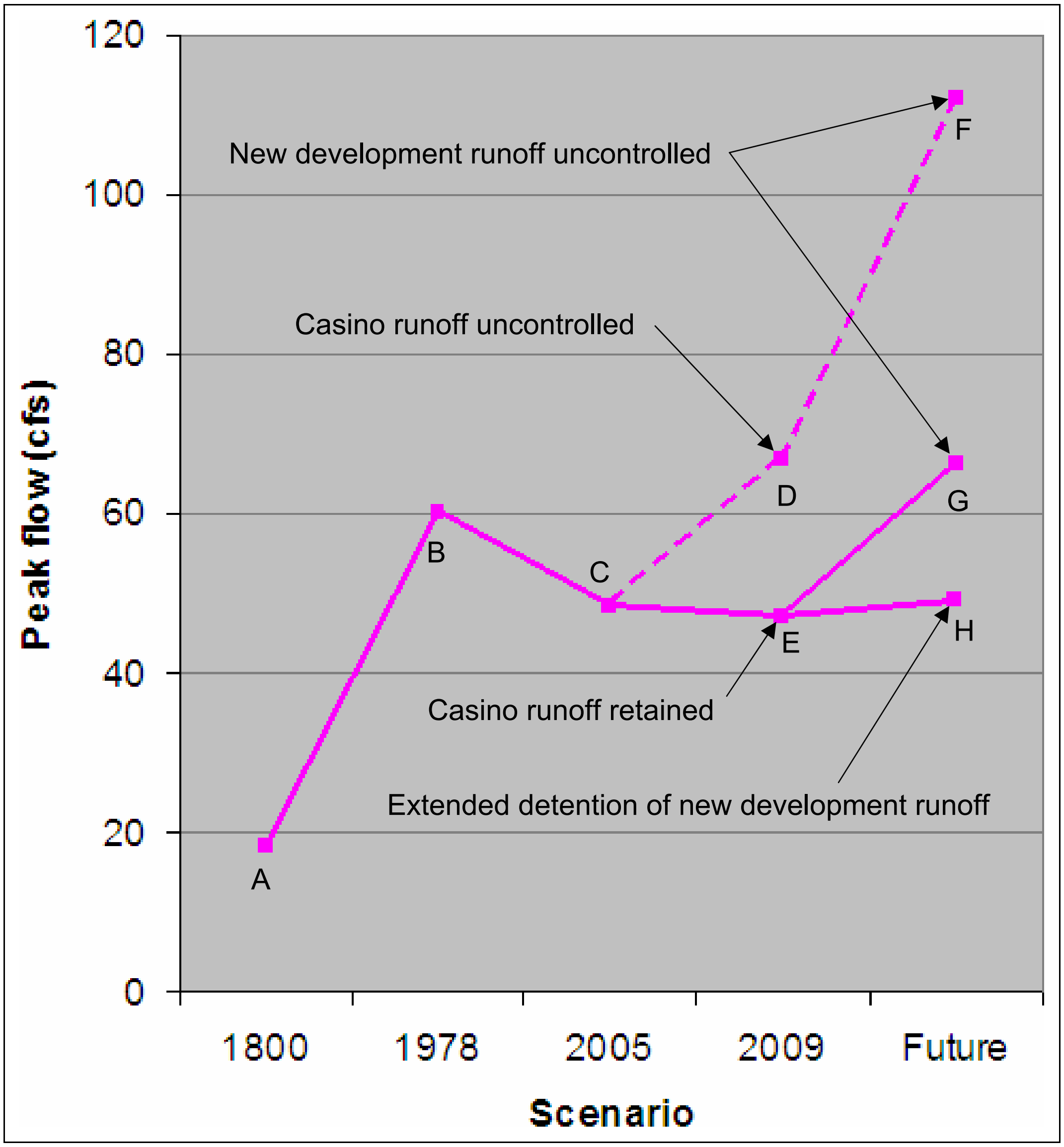


Figure 17 – Peak Flows for Dickinson Creek at Michigan Avenue

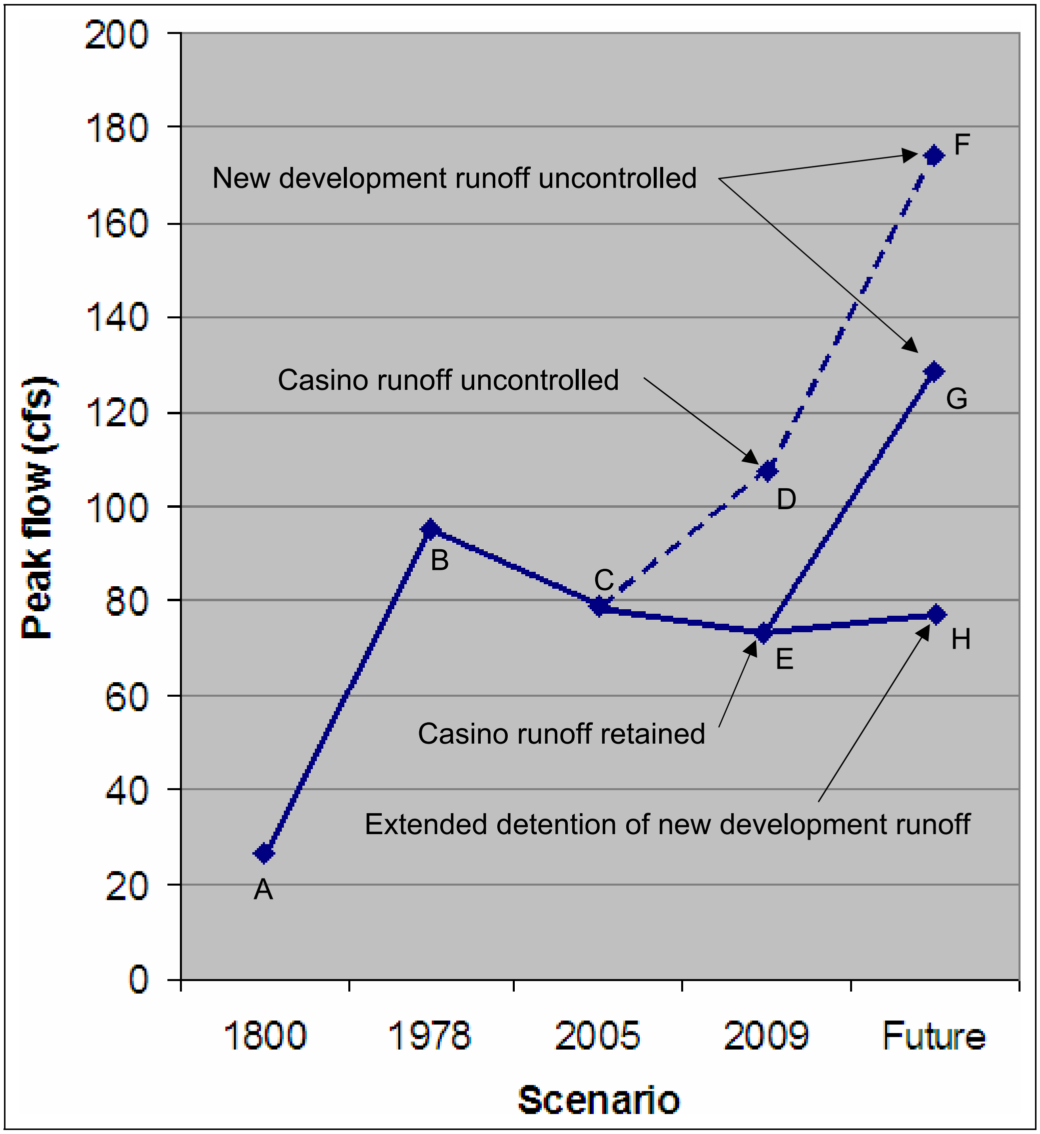


Figure 18 – Peak Flows for Dickinson Creek near the mouth

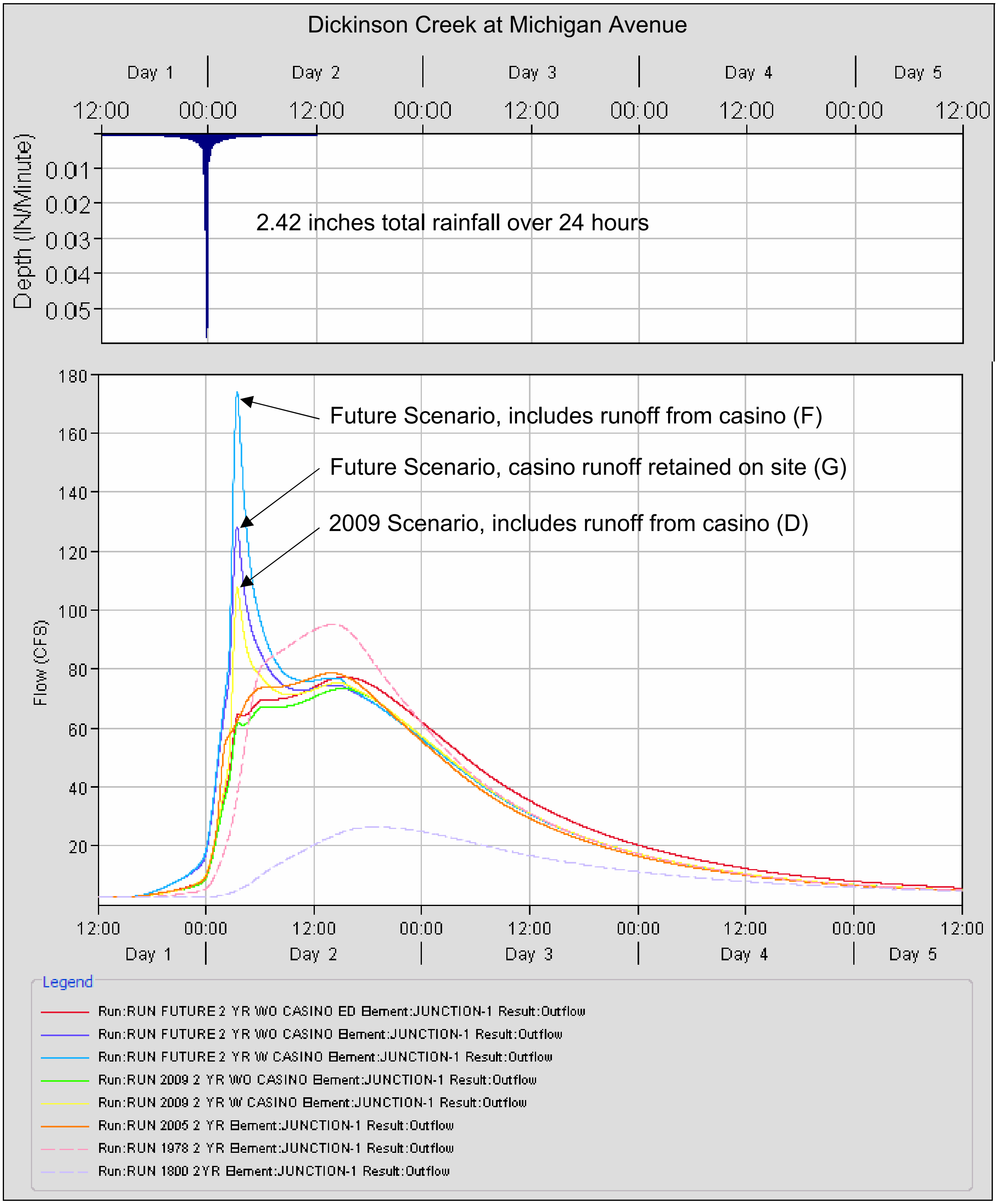


Figure 19 – Hydrographs for Dickinson Creek at Michigan Avenue

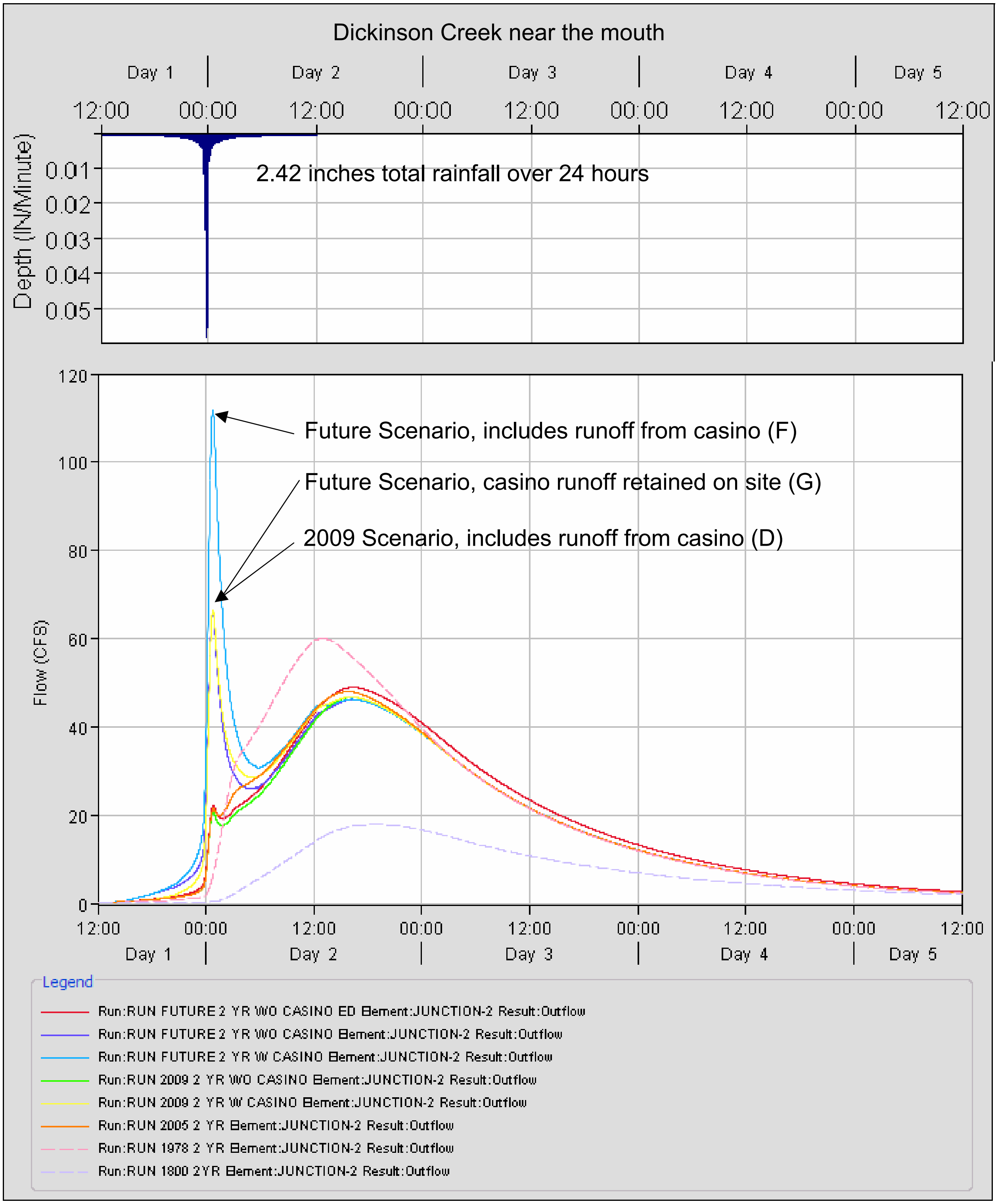


Figure 20 – Hydrographs for Dickinson Creek near the mouth

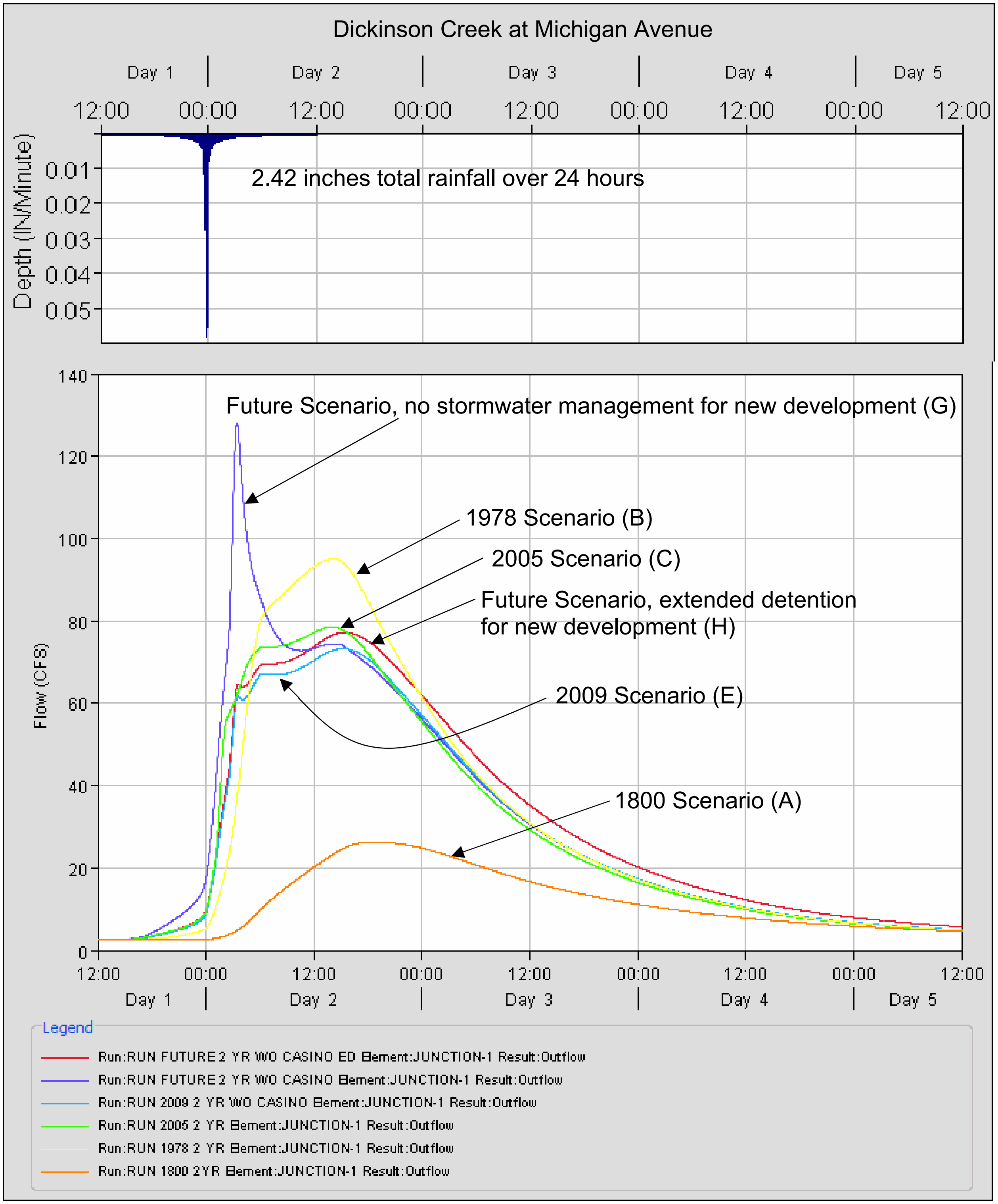


Figure 21 – Selected Hydrographs for Dickinson Creek at Michigan Avenue

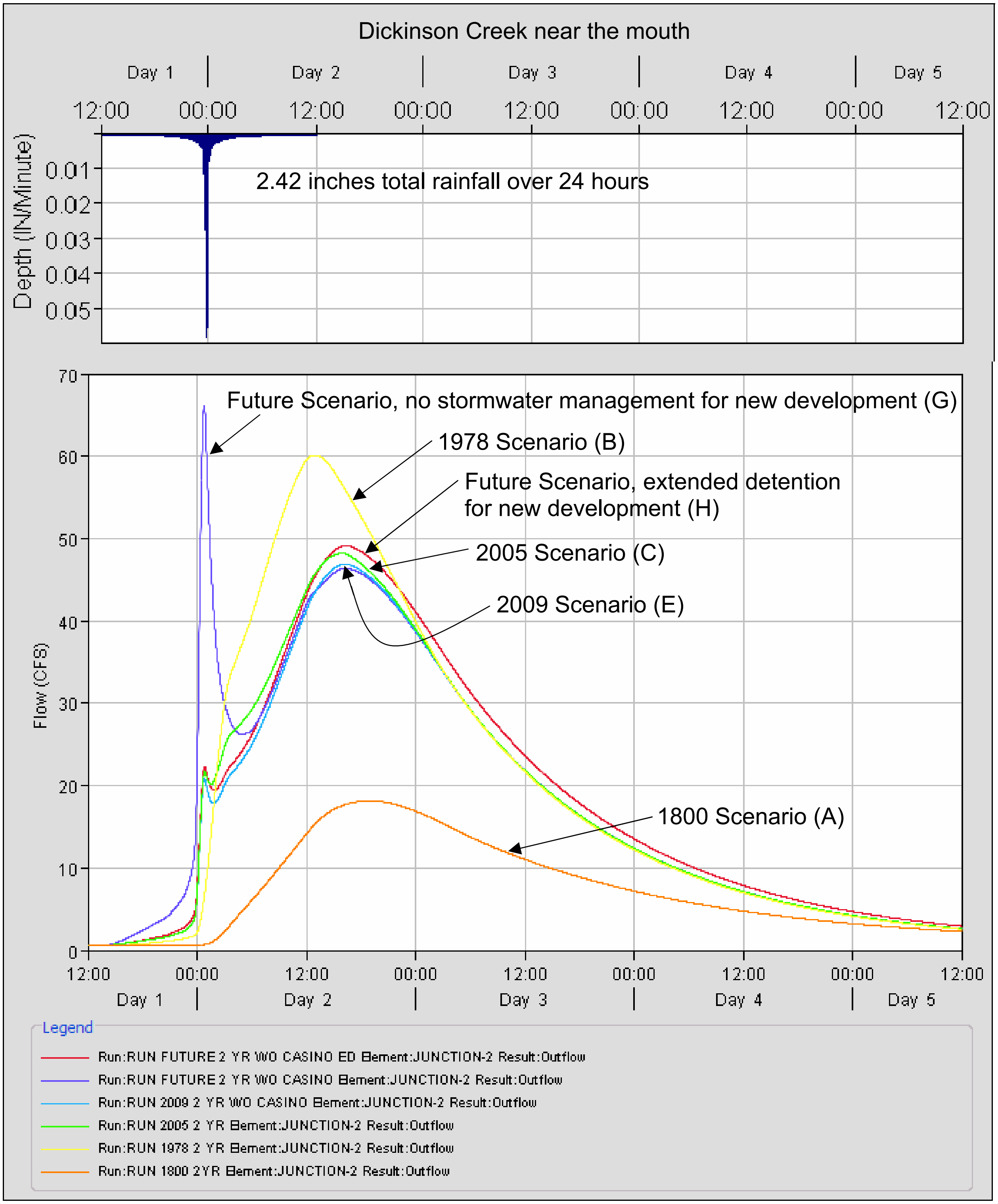


Figure 22 – Selected Hydrographs for Dickinson Creek near the mouth

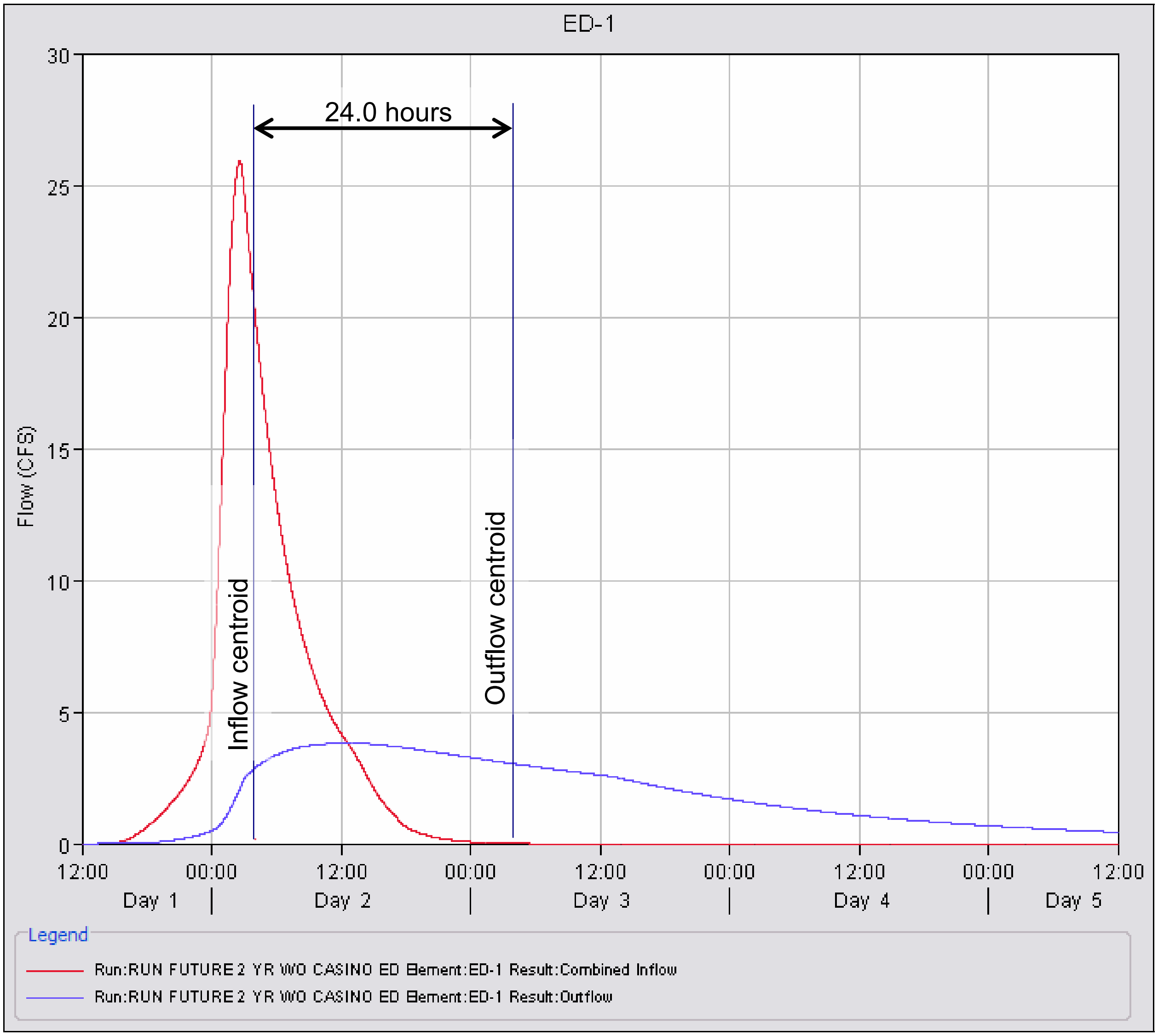


Figure 23: Hydrographs for Extended Detention, Future Scenario H, Subbasin 1, illustrating the change in the hydrographs' centroids (half of the water volume is on each side of the centroid)

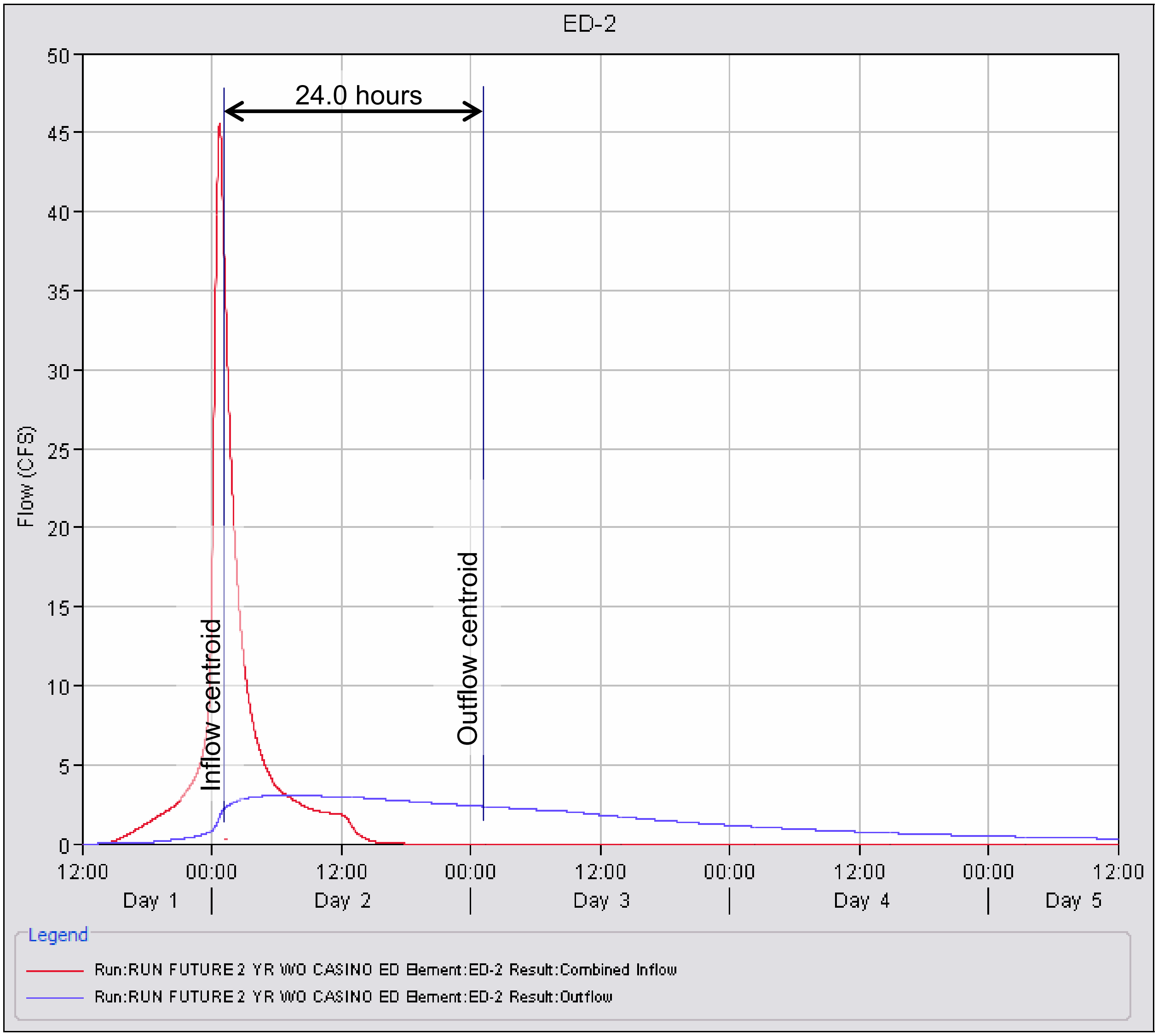


Figure 24: Hydrographs for Extended Detention, Future Scenario H, Subbasin 2, illustrating the change in the hydrographs' centroids (half of the water volume is on each side of the centroid)

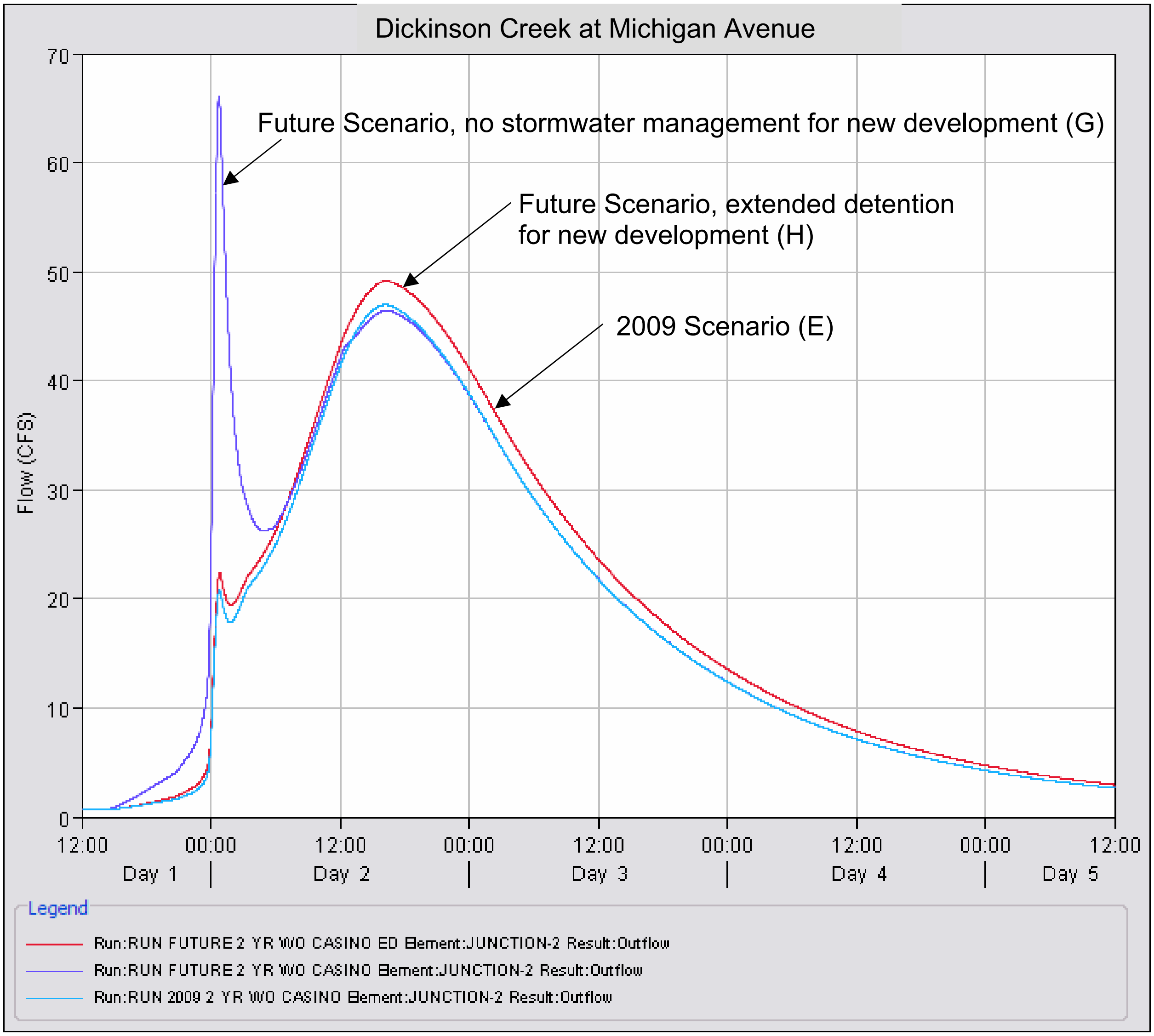


Figure 25: In-stream Hydrographs for Dickinson Creek at Michigan Avenue illustrating the effects of expected development with and without 24-hour extended detention

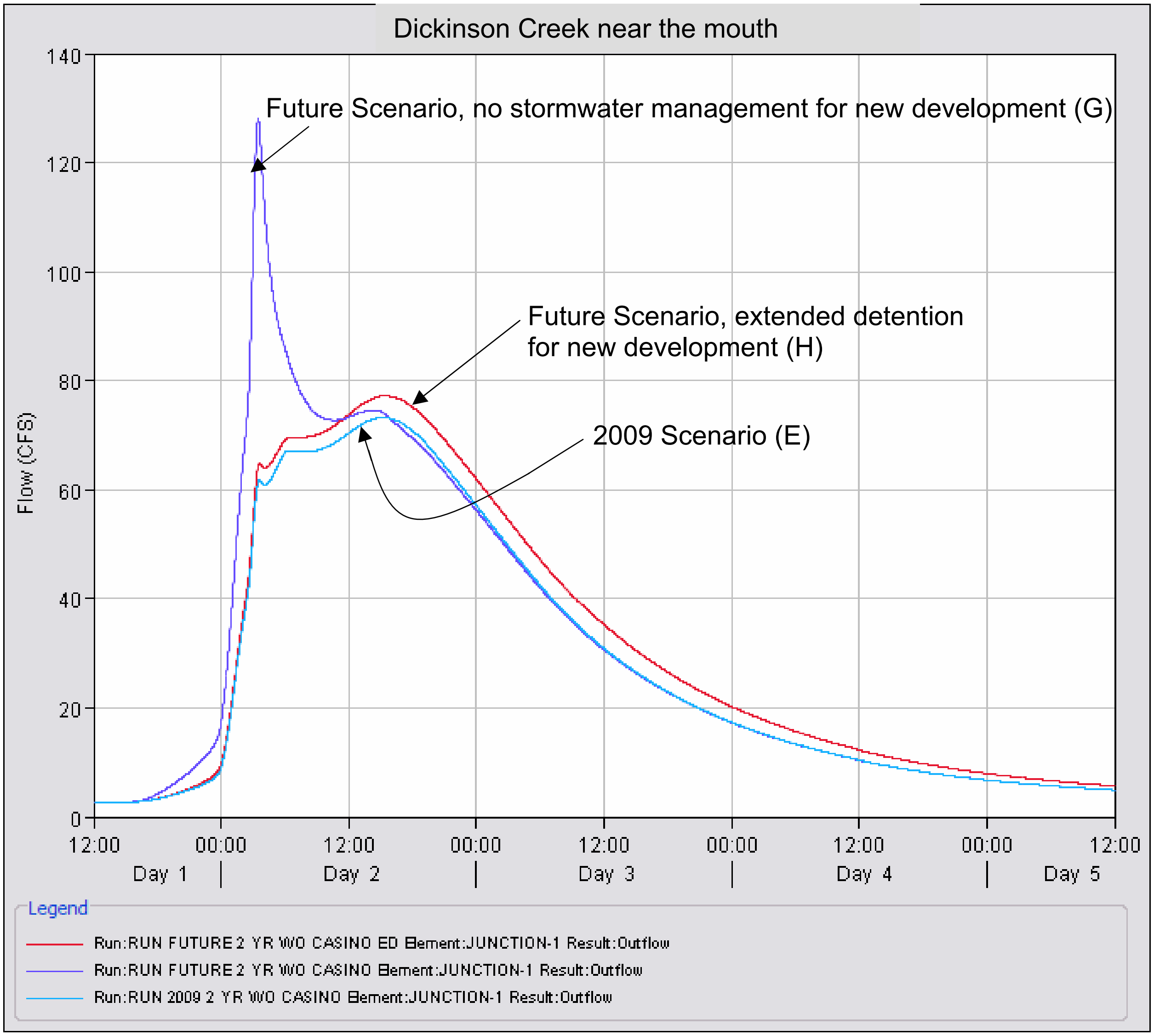


Figure 26: In-stream Hydrographs for Dickinson Creek near the mouth illustrating the effects of expected development with and without 24-hour extended detention

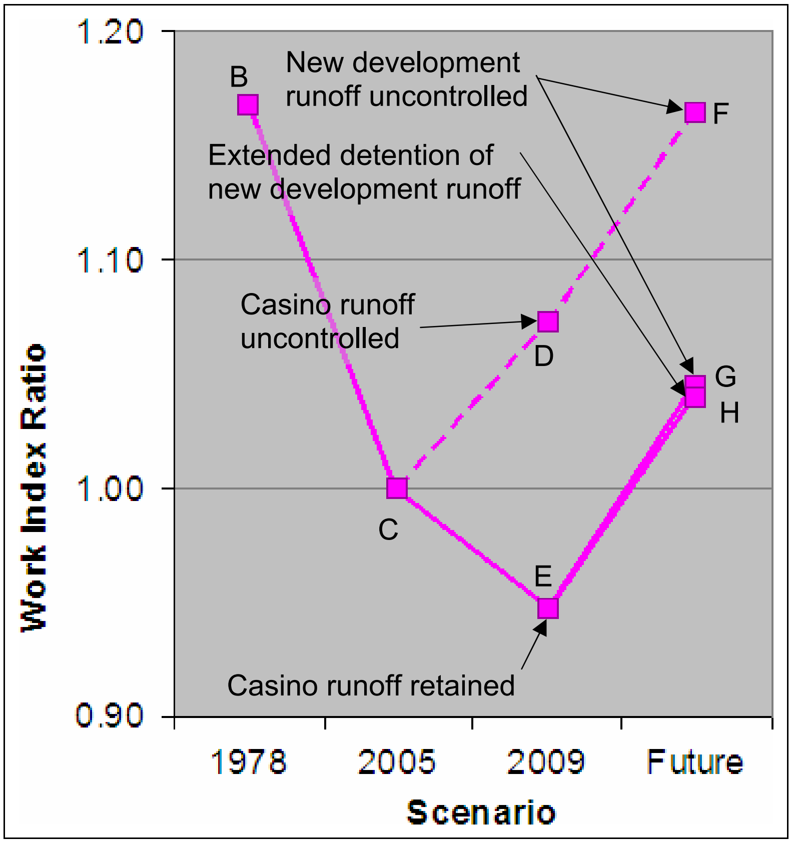


Figure 27 – Stream Power Ratios for Dickinson Creek at Michigan Avenue

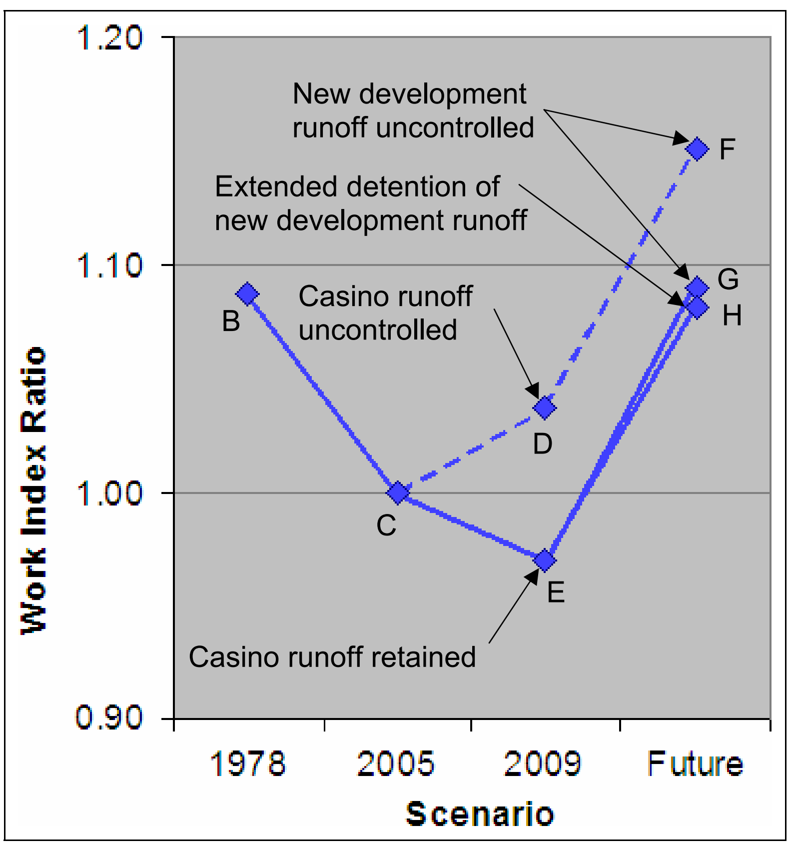


Figure 28 – Stream Power Ratios for Dickinson Creek near the mouth

Morphologic Analysis

Overview

Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades (fills in) nor degrades (erodes). A stable stream is in dynamic equilibrium, defined as "an open system in a steady state in which there is a continuous inflow and output of materials, in which the form or character of the system remains unchanged." (Rosgen, 2006).

Stream stability is often depicted as a balance between sediment load, sediment size, stream slope, and stream discharge, Figure 29. The stream morphology will adapt so that the left side of the equation in Figure 29 balances the right side. An increase in discharge, especially channel-forming flows, increases the stream's ability to move larger stone and soil particles, and promotes increased channel meandering and lateral bank erosion as the channel attempts to decrease its slope and enlarge its channel to restore balance.

Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural. An unstable stream is characterized by excessive, extensive erosion, with surplus sediment accumulating downstream, typically near the stream's mouth or in a lake.

Simon (1989) defined six stages of channel evolution, Table 13. The stages describe a stream's erosive evolution, starting with a stable channel (stage I) and ending with a refilled channel (stage VI). In between, the stream is disturbed by urbanization, forest clearing, dam construction, etc.

Table 13 – Stages of Channel Evolution

Stage	Stream Condition
I	Stream is stable.
II	Watershed's hydrologic characteristics change – forest clearing, urbanization, dam construction, channel dredging, etc.
III	Channel instability sets in with scouring of the bed.
IV	Bank erosion and channel widening occur.
V	Banks continue to cave into the stream, widening the channel. The stream also accumulates sediment from upstream erosion.
VI	Re-equilibrium occurs and bank erosion ceases. Riparian vegetation becomes established.

It is beyond this study's scope to identify the evolutionary stage of a specific reach of the Dickinson Creek or its tributaries.

Future hydrologic changes can further impact stream morphology, as well as water quality. These changes can be moderated with effective stormwater management techniques, such as treatment of the "first flush" runoff, wetland protection, retention and infiltration of excess runoff, LID techniques, and properly designed detention of runoff from low probability storms. Refer to the Stormwater Management section for more detail.

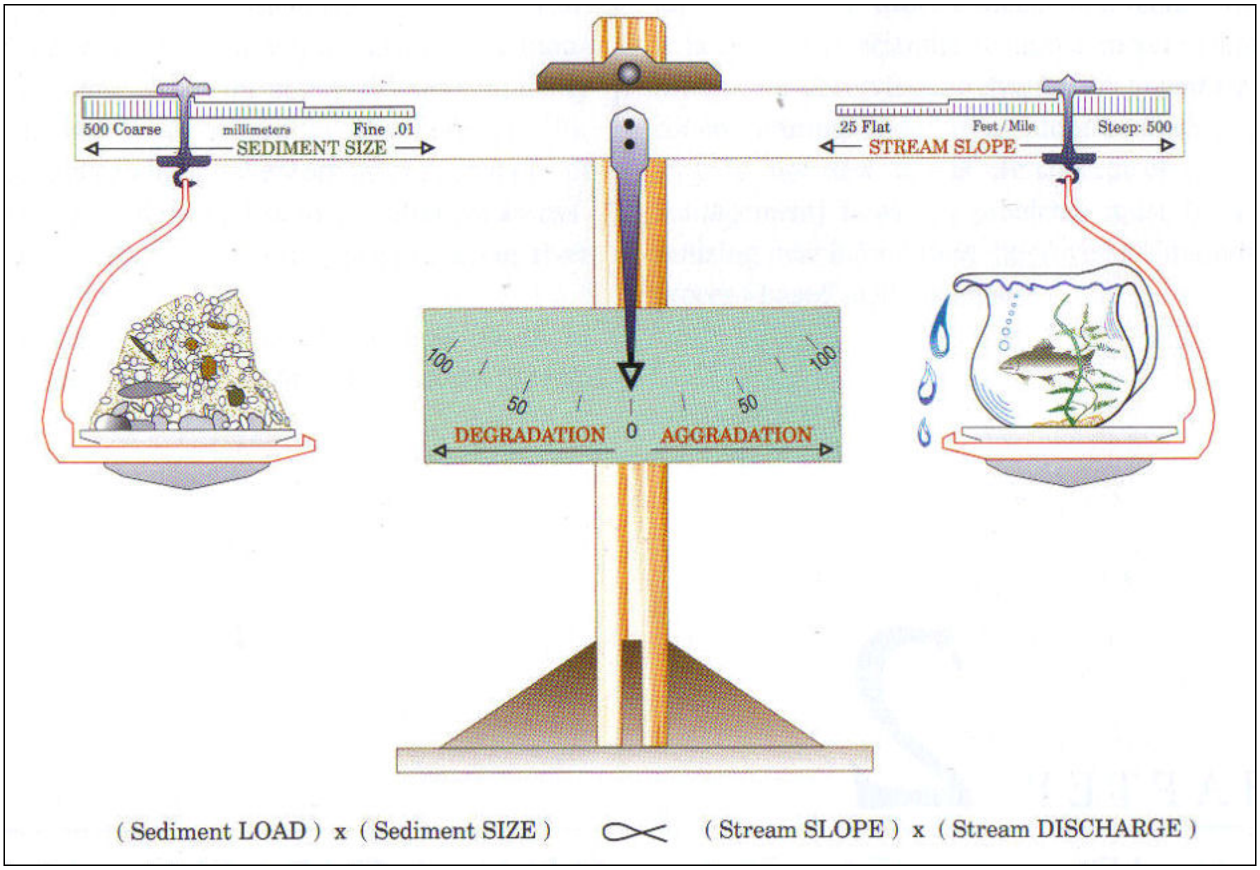


Figure 29 – Generalized Stable Channel Relationship proposed by Lane in 1955 (illustration from Rosgen 1996)

Bank Erosion Hazard Index (BEHI) Analysis

HSU staff conducted a Bank Erosion Hazard Index (BEHI) analysis along Dickinson Creek at Michigan Avenue and near the mouth. The analysis follows the BEHI procedure detailed on pages 5-54 through 5-64 in the book "Watershed Assessment of River Stability and Sediment Supply (WARSSS)" (Rosgen, 2006). BEHI is a procedure for evaluating streambank susceptibility to erosion. Table 14 provides a summary of the BEHI scores. Details for each site follow.

Table 14 – Summary of BEHI scores

Location	BEHI Scores	Bank Erosion Hazard
Dickinson Creek at Michigan Avenue	21.1 – 35.6	Moderate to High
Dickinson Creek at Historic Bridge Park	18.5 – 34.6	Low to High

Dickinson Creek at Michigan Avenue

BEHI scoring for Dickinson Creek at Michigan Avenue, Figures 30 and 31, is shown in Table 15. The sites score moderate to high, in part because of the amount of sand on the banks. It is possible that construction in the area is contributing an excess sand load, and the current conditions are therefore not typical. The score for site #2 is also high because of the high, steep, nearly bare, streambank, Figure 31.

Table 15 – BEHI Scoring, Dickinson Creek at Michigan Avenue

	Site 1		Site 2	
	Value	BEHI score	Value	BEHI score
Bank/Bankfull Height	1	1.0	10	10.0
Root Depth/Bank	0.71	2.5	0.95	1.0
Root Density	71	2.5	28.5	5.5
Bank Angle	22°	2.1	45°	3.1
Surface Protection	66%	3.0	30%	6.0
Bank Material Adjustment	Sand	10.0	Sand	10.0
Stratification Adjustment		0.0		0.0
Total BEHI Score		21.1		35.6
Bank Erosion Potential	**Moderate**		**High**	

Figure 30 – Dickinson Creek, Michigan Avenue, Left Bank: BEHI evaluation site 1

Figure 31 – Dickinson Creek, Michigan Avenue, Right Bank: BEHI evaluation site 2

Dickinson Creek near its mouth

The condition of Dickinson Creek near its mouth, in the Historic Bridge Park, is more variable than upstream. The BEHI scoring for the reach is shown in Table 16. The reach starts just below a railroad overpass with a straight, steep reach, site 1, as shown in Figure 32. During flow measurements for this study, water velocities as high as 4.7 feet per second were measured here. Below this reach, the creek is highly meandering, with some undercut banks, site 2, Figure 33. The high velocities entering the meandered section cause the highest BEHI scores in this study. Some of the meanders were cut off this year, Figure 34, apparently by the high flows in September. Below the meanders, the creek becomes flatter and straighter, as it begins to be affected by the stage of the Kalamazoo River.

Table 16 – BEHI Scoring, Dickinson Creek at the Historic Bridge Park near the mouth

	Site 1		Site 2	
	Value	BEHI score	Value	BEHI score
Bank/Bankfull Height	1.35	4.0	1.0	1.0
Plant Root Depth	0.88	2.0	0.35	5.0
Root Density	88%	1.0	35	5.0
Bank Angle	10°	1.5	100°	8.6
Surface Protection	100	0.0	35%	5.0
Bank Material Adjustment	Sand	10.0	Sand	10.0
Stratification Adjustment		0.0		0.0
Total BEHI Score		18.5		34.6
Bank Erosion Potential	**Low**		**High**	

Figure 32 – Dickinson Creek, Historic Bridge Park: BEHI evaluation site 1

Figure 33 – Dickinson Creek, Historic Bridge Park: BEHI evaluation site 2

Figure 34 – Dickinson Creek, Historic Bridge Park: meander cut-offs near BEHI evaluation site 2

Tractive Force Analysis

This tractive force analysis uses a simplified shear stress equation to estimate channel stability. The equation assumes uniform flow in a straight channel with typical hydraulic roughness, which excludes heavily vegetated channels. Bends, local turbulence, and smoother channels can all increase the particle size mobilized above the calculated value. The equation is explained in detail in Appendix E.

Channel stability is estimated by comparing the calculated incipient particle diameter (IPD) that moves at bankfull flow to the measured IPD, as shown in Table 17. The measured IPD is the diameter at which either 50 or 84 percent of the measured channel bed particles are smaller (D_{50} and D_{84}, respectively). Both D_{50} and D_{84} have been used in this method, although D_{84} may be more prevalent. The results for Dickinson Creek are summarized in Table 18 and detailed in Table 19.

At Michigan Avenue, the size of the particle that should be mobilized at bankfull flow is higher than most of the bed material. This could indicate instability or that construction in the area is contributing an excess sand load, which could mean that current bed material conditions are not typical. The stream power and particle size mobilized at site 1, Figure 32, in the Historic Bridge Park is much higher than at Michigan Avenue. Based on aerial photos and field observations, this reach in the park is likely not typical for the stream. The particle size mobilized closer to the mouth drops off dramatically as the stream slope flattens out and the water depth is affected by the Kalamazoo River stage.

The site with erosion potential in the tractive force analysis, Dickinson Creek at Michigan Avenue, also has moderate to high bank erosion hazard index values, but there is some uncertainty in those results because of extensive construction activities in the vicinity. The riffle at site 1 in the Historic Bridge Park has a low bank erosion hazard index value and is approximately in equilibrium, according to the tractive force analysis. The tractive force analysis does not correlate well with the BEHI analysis for the location near the mouth – a high bank erosion hazard index value but tractive force analysis indicates approximate equilibrium. This location may be affected by the stage of the Kalamazoo River and is apparently a deposition zone when the Kalamazoo River is high, but subject to erosive flows during some high Dickinson Creek flows.

Table 17 – Interpretation of Tractive Force Analysis

Calculated IPD << Measured IPD	Potential Deposition
Calculated IPD ≈ Measured IPD	Approximate Equilibrium
Calculated IPD >> Measured IPD	Potential Erosion

Table 18 – Tractive Force Analysis at Three Dickinson Creek Sites

Dickinson Creek Location	Incipient Particle Diameter (cm)		Estimated Channel Stability
	Calculated	Measured	
Michigan Avenue	0.90	0.10 – 0.32	Potential Erosion*
Historic Bridge Park, Riffle	6.6	1.7 – 6.9	Approximate Equilibrium
Historic Bridge Park, near mouth	0.2	0.025 – 0.2	Approximate Equilibrium

*The NPS program is initially using calculated IPD/measured D_{84} IPD > 1.7 as an indicator of potential erosion.

Table 19 – Tractive Force Analysis Details

Location	Tractive Force – Calculated IPD	Bed Material – Measured IPD
at Michigan Avenue	Slope = 0.00174	D_{50} = 0.10 cm D_{84} = 0.32 cm
	Bankfull Depth = 1.7 ft x 305mm/ft = 519 mm	
	IPD (cm) = BFdepth (mm) x Slope = 0.90 cm	
Riffle in Historic Bridge Park	Slope = 0.0128	D_{50} = 1.7 cm D_{84} = 6.9 cm
	Bankfull Depth = 1.7 ft x 305 mm/ft = 519 mm	
	IPD (cm) = BFdepth (mm) x Slope = 6.6 cm	
Near mouth in Historic Bridge Park	Slope = 0.000467 ft/ft	Medium to Very Coarse Sand 0.025 – 0.2 cm
	Bankfull Depth = 1.7 ft x 305mm/ft = 519 mm	
	IPD (cm) = BFdepth (mm) x Slope = 0.2 cm	

Recommendations

A river or stream is affected by everything in its watershed. Watershed planning, however, must identify critical areas to focus limited technical and financial resources on the parts of the watershed contributing a disproportionate share of the pollutants. If not properly managed, runoff from future development in the middle and lower watershed has the potential to increase channel-forming peak flows, and to increase the frequency of those flows, because the impervious areas may, by themselves, often generate higher peak flows than the entire watershed would have previously.

The hydrologic analysis indicates channel-forming flows have been declining, but may increase in the future due to urbanization. BEHI analysis indicates moderate to high bank erosion potential at Michigan Avenue. Tractive Force analysis indicates that stream power exceeds the resistance of most of the channel bed material, also indicating potential erosion. The stream channel may be adapting to a higher flow regime, or the results may be distorted by excess sand load from construction in the area. BEHI analysis indicates low to high bank erosion potential near the mouth. Tractive Force analysis indicates that stream power approximately equals the resistance of most of the channel bed material, indicating approximate equilibrium. The most actively eroding reach is apparently an isolated problem, but the meander cutoffs that occurred during 2008 illustrate the potential rate of the stream's response to erosive flows.

Protecting this stream from both higher flows and longer durations of channel-forming flows is important to prevent destabilizing the stream channel. Unless the increased runoff can be mitigated by infiltrated or reuse, extended duration of higher flows is likely.

Stormwater Management

When precipitation falls, it can infiltrate into the ground, evapotranspirate back into the air, or run off the ground surface to a water body. It is helpful to consider three principal runoff effects: water quality, channel shape, and flood levels, as shown in Figure 35.

Figure 35 – Runoff Impacts

Land use changes that reduce evapotranspiration and infiltration increase runoff. One reason low impact development has become increasingly popular is that it avoids creating more runoff; intercepting and infiltrating the excess runoff instead.

Runoff from small rainfall events and the first portion of the runoff from larger events is termed the “first flush”, because it carries the majority of the pollutants. For more information, refer to the Water Quality section.

Larger, but frequent, storms or snowmelts produce the flows that shape the channel. These relatively modest storm flows, because of their higher frequency, have more effect on channel form than extreme flood flows. Hydrologic changes that increase this flow can cause the stream channel to become unstable. Stormwater management techniques used to mitigate flooding can also help mitigate projected channel-forming flow increases. However, channel-forming flow criteria should be specifically considered in the stormwater management plan so that the selected BMPs will be most effective. For example, detention ponds designed to control runoff from the 4 percent chance, 24-hour storm may do little to control the runoff from the 50 percent chance, 24-hour storm, unless the outlet is specifically designed to do so. For more information, refer to the Stream Channel Protection section.

Increases in the runoff volume and peak flow from large storms, such as the 4 percent chance (25-year), 24-hour storm, could cause or aggravate flooding problems unless mitigated using effective stormwater management techniques. For more information, refer to the Flood Protection section.

Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 36 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first flush." Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. The volume of runoff recommended for treatment is calculated as follows:

- **0.5 inch of runoff** from a single impervious area. This criteria was one of the first to define the “first flush” phenomenon by studying runoff from parking lots. It has been widely used as the design water quality volume. Additional research has found that this criterion for water quality volume only applies to the runoff from a single impervious area, such as the parking lot to a single development. It is the minimum value that could be expected to capture the runoff containing the most pollutants. It is not appropriate to use for a mixture of impervious areas and pervious areas. It is also not appropriate to use for multiple impervious areas treated by a single BMP or multiple BMPs. Although it may have applications in some limited circumstances, it is not recommended that this method be used to calculate water quality volume.

- **1 inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas**. This method provides reasonable certainty that the runoff containing the majority of pollutants from impervious areas is captured and treated by applying a simple calculation. It assumes that disturbed pervious areas contribute less runoff and therefore less pollutant to the BMPs selected. This method is recommended when the percentage of impervious area on a site is small and both pervious and impervious areas are treated by the same BMP.

- **1 inch of runoff from disturbed pervious and impervious areas**. The most conservative water quality volume calculated with a simple formula. It virtually assures that all of the first flush from any site will be captured and treated. However, when calculated this way, the water quality volume may exceed the channel protection volume. This volume determined using this method should always be compared to the channel protection volume to determine if additional water quality treatment is necessary. This method is recommended when the amount of pervious area is small or when it is desired to obtain the most conservative estimate of volume needing treatment.

- **90% of runoff producing storms.** This method determines the water quality volume by calculating the runoff generated from the 90 percent non-exceedance rain event for the entire site. In Michigan, that event varies from 0.77 to 1.00 inches. For the Dickinson Creek watershed climatic regions, the calculated value is 1.00 inches. This method provides a more rigorous analysis based on the site's hydrologic response. To accurately represent the pervious portion of runoff needing treatment, the runoff calculation for this method must use the small storm hydrology method described in www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf. The water quality volume calculated in this way produces a lower volume than using 1 inch of runoff but still assures treatment of the first flush. This method is recommended when a precise estimate of water quality volume is desired or for multiple, distributed sites treated by one BMP.

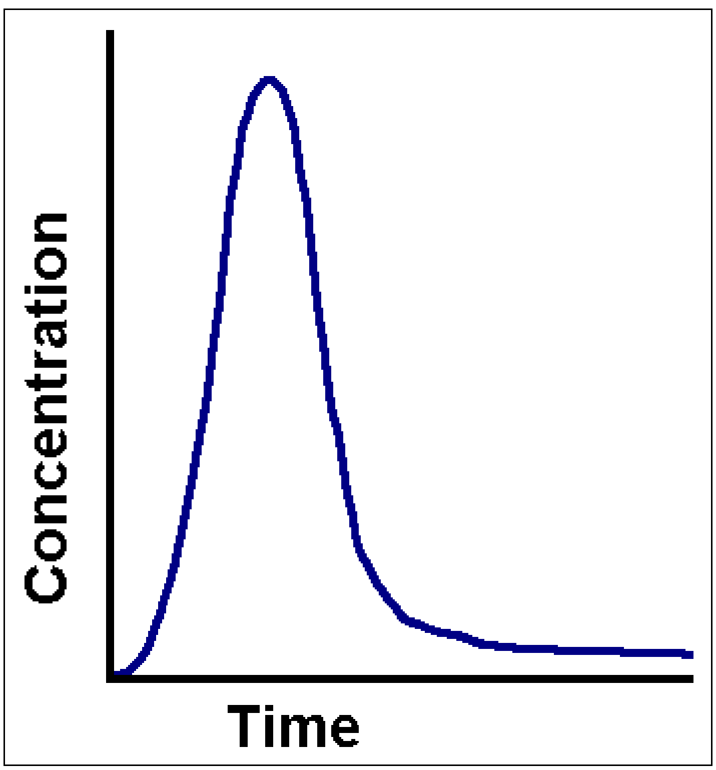


Figure 36 – Plot of Pollutant Concentration versus Time

Stream Channel Protection

A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades or degrades. Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural.

Possible causes of erosion are:

- Natural river dynamics
- Sparse vegetative cover due to too much animal or human traffic
- Concentrated runoff adjacent to the streambank, i.e. gullies, seepage
- In-stream flow obstructions, i.e. log jams, failed bridge supports
- An infrequent event, such as an ice jam or low probability flood
- Unusually large or frequent wave action
- A significant change in the watershed's hydrologic characteristics (typically land use)
- A change in the stream form impacting adjacent portions of the stream, i.e. dredging, channelization

An assessment of the cause(s) of erosion is necessary so that proposed solutions will be permanent and do not simply move the erosion problem to another location. The first six listed causes can produce localized erosion. Either of the last two causes, however, could produce a morphologically unstable stream. Symptoms of active channel enlargement in an unstable stream include:

- Down-cutting of the channel bottom
- Extensive and excessive erosion of the stream banks
- Erosion on the inside bank of channel bends
- Evidence in the streambanks of bed erosion down through an armor layer
- Exposed sanitary or storm sewers that were initially installed under the stream bed

Erosion in a morphologically unstable stream is caused by increases in the relatively frequent channel-forming flows that, because of their higher frequency, have more effect on channel form than extreme flood flows. As shown in Figure 37, multiplying the sediment transport rate curve (a) by the storm frequency of occurrence curve (b) yields a curve (c) that, at its peak, indicates the flow that moves most of the sediment in a stream. This flow is termed the effective discharge. The effective discharge usually has a one- to two-year recurrence interval and is the dominant channel-forming flow in a stable stream.

Increases in the frequency, duration, and magnitude of these flows cause stream bank and bed erosion as the stream adapts. According to the Stream Corridor Restoration manual, stream channels can often enlarge their cross-sectional area by a factor of 2 to 5 (FISRWG, 10/1998). In Dynamics of Urban Stream Channel Enlargement, The Practice of Watershed Protection, ultimate channel enlargement ratios of up to approximately 10 are reported, as shown in Figure 38 (Schueler and Holland, 2000). To prevent or minimize this erosion, watershed stakeholders should specifically consider stormwater management to protect channel morphology. Low impact development and infiltration BMPs can be incorporated to offset flow increases. Stormwater management ordinances can specifically address channel protection. However, where ordinances have included channel protection criteria, it has typically been focused on controlling peak flows from the 2-year storm.

The nationally recognized Center for Watershed Protection asserts that 24-hour extended detention for runoff from 1-year storms better protects channel morphology than 2-year peak discharge control, because peak discharge control does not reduce the frequency of erosive bankfull and sub-bankfull flows that often increase as development occurs within the watershed. Indeed, it may actually increase the duration of these erosive, channel-forming flows. The intent of 24-hour extended detention for runoff from 1-year storms is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 39. A few watershed plans funded through the MDEQ Nonpoint Source Program have recommended requirements based on this criterion. One such example is from the Anchor Bay Technical Report, shown in Figure 40. This analysis, which is for climatic region 10, is for 2.06 inches of rainfall. The Dickinson Creek watershed is in climatic regions 9, which has a 50 percent chance (2-year) 24-hour storm design rainfall value of 2.42 inches, as tabulated in Rainfall Frequency Atlas of the Midwest, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. The MDEQ Nonpoint Source Program is funding this analysis for western Michigan through the Lower Grand Initiatives grant, 2007-0137, to the Grand Valley Metropolitan Council.

Detention designed to control channel-forming flows and prevent streambank erosion may not be needed for runoff routed through storm sewers to a large river if the runoff routed through the storm sewers enters the river well ahead of the peak flow in the river. In this case, the management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

Hydrologic and hydraulic modeling may be justified to determine if runoff from a drainage area should be limited, either by detention or infiltration, to prevent flow or flood level increases or to verify that flood peaks are not increased due to the timing of the peak flows from detention ponds and in the stream.

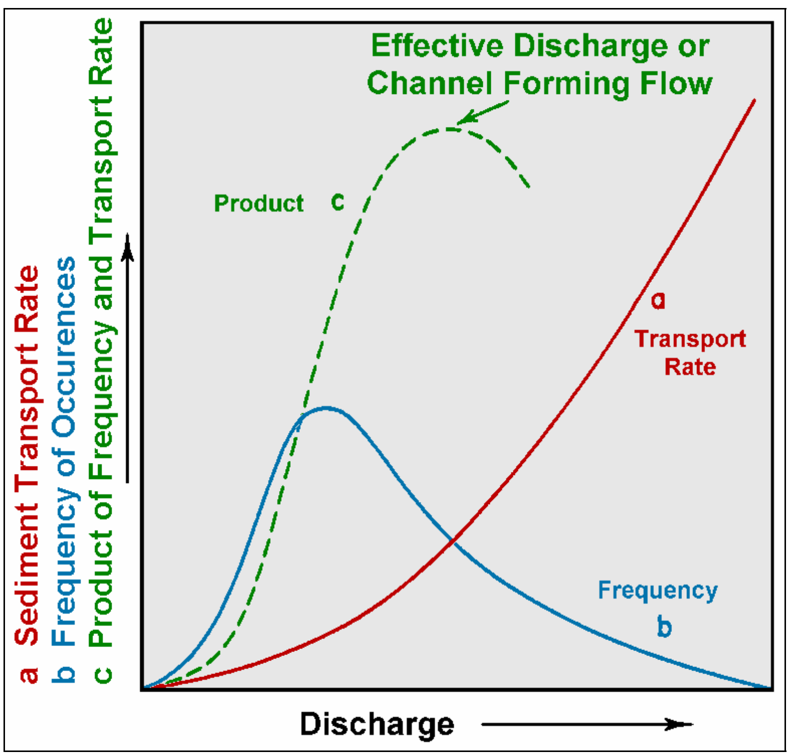


Figure 37 – Effective Discharge (from Applied River Morphology. 1996. Dave Rosgen)

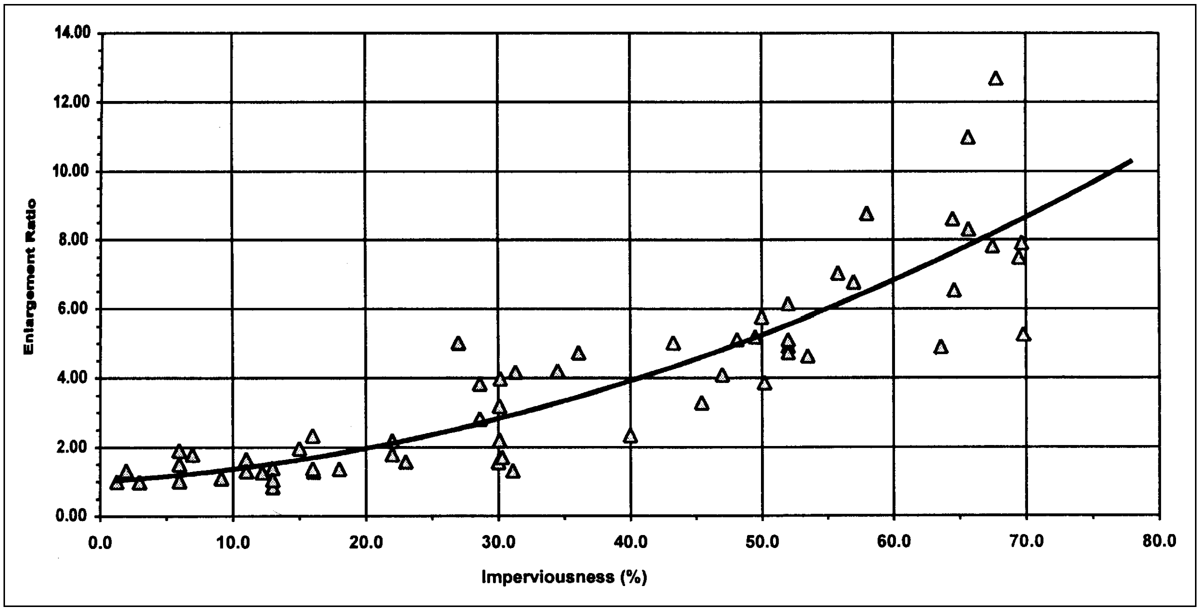


Figure 38 – "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From The Practice of Watershed Protection, Thomas R. Schueler and Heather K. Holland, 2000)

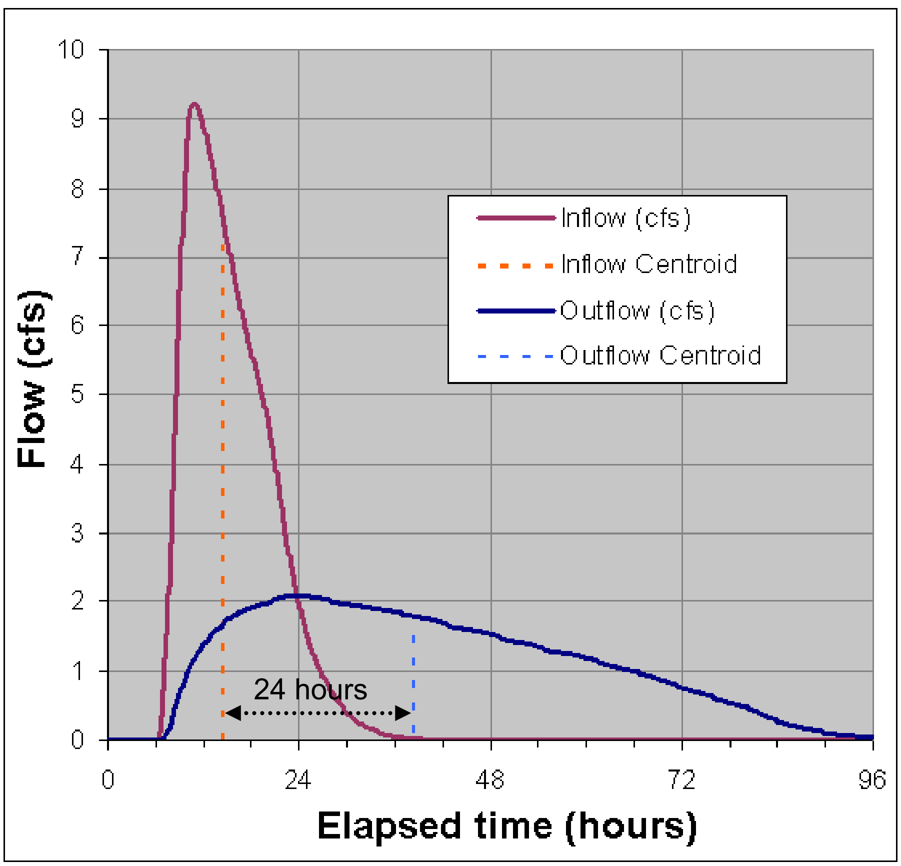


Figure 39 – Example of 24-hour extended detention criterion applied to detention pond design

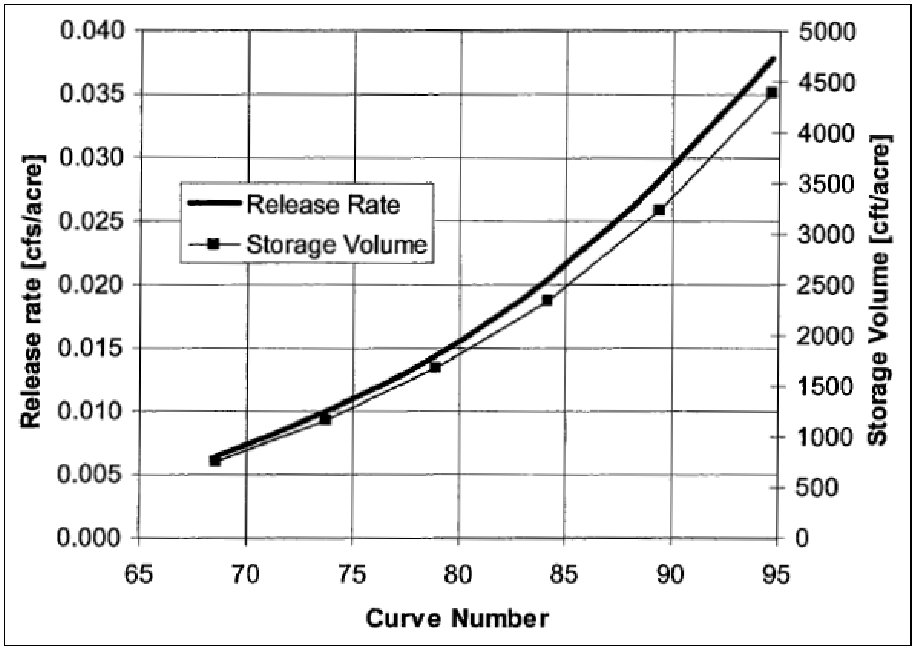


Figure 40 – Example of detention pond requirements derived from the 24-hour extended detention criterion

Flood Protection

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions and putting people, homes, and other structures at risk, Figure 41. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

Figure 41 – Mason County Flooding, June 2008, photo courtesy of Raymond Holt, Michigan State Police

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Appendix A: Dickinson Creek Hydrologic Parameters

The watershed was modeled using HEC-HMS 3.2 to calculate surface runoff volumes and peak flows. This appendix is provided so that the model may be recreated.

Table A1 provides the hydrologic parameters that were specified for each of the subbasin elements in the HEC-HMS model, Figure A1. The initial loss fields in the HEC-HMS model were left blank so that the model uses the standard equation based on the curve number. The storage coefficient for each subbasin was initially set equal to the associated time of concentration, Table A1. Peak flows, calculated with HEC-HMS using these parameters, were multiplied by the ponding adjustment factors listed in Table 9 to incorporate flow attenuation by storage in the subbasin. Revised values for the storage coefficients, Table A1, were iteratively calculated to provide the ponding-adjusted peak flows. Table A2 provides the hydrologic parameters that were specified for the reservoirs that simulate the 24-hour detention of stormwater runoff from future development. Table A3 provides the hydrologic parameters that were specified for the reach routing.

Baseflow was included in the model based on model calibration. Modeled baseflow is 2.00, 0.08, and 0.56 cfs for subbasins 1, 2, and 3 respectively.

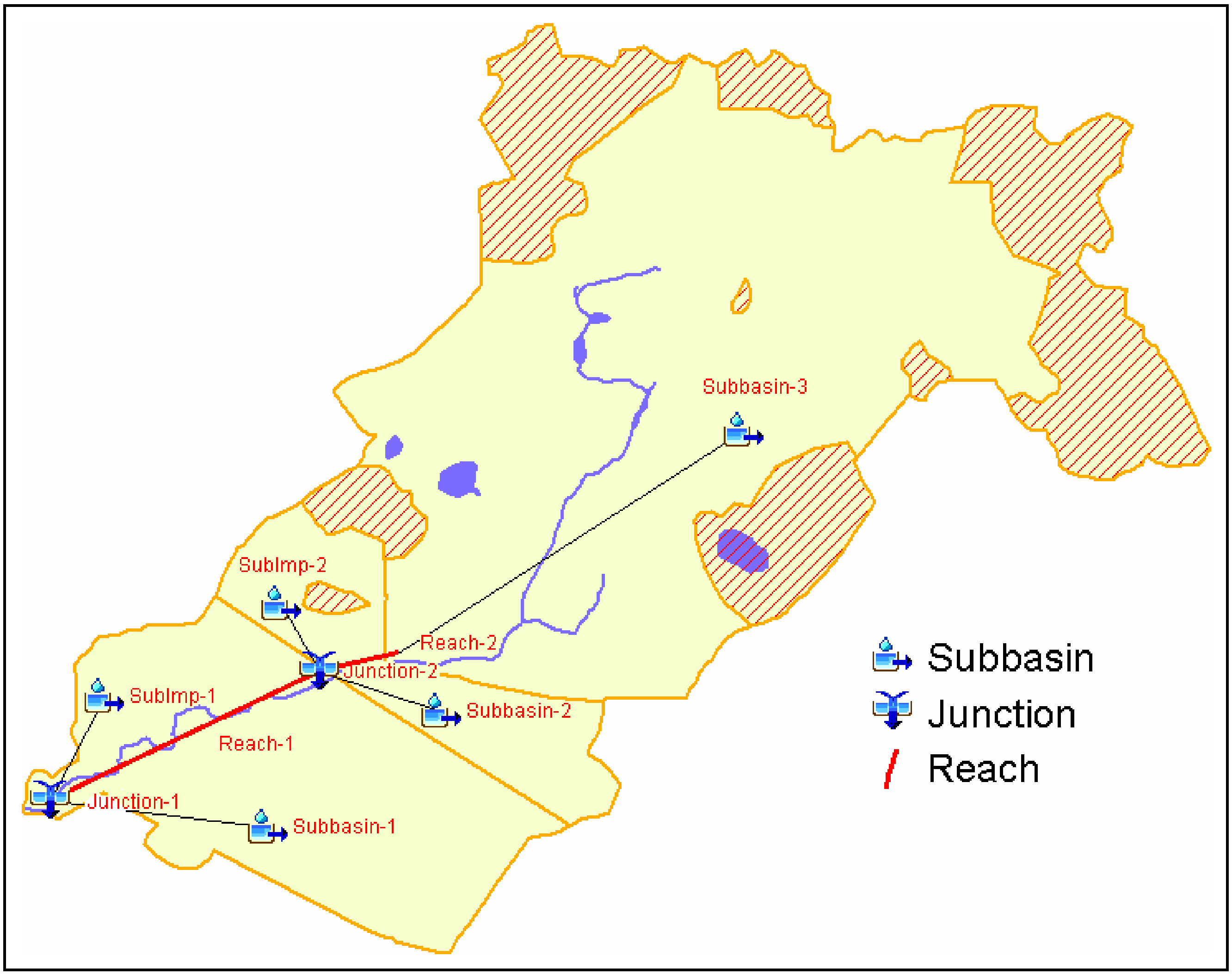

Figure A1: HEC-HMS Hydrologic Model Overview, 2005 Model Scenario shown

Table A1 – Subbasin Parameters

Scenario	Subbasin	Element	DA (sq. mi.)	CN (ARC II)	Tc (hours)	SC
A. 1800	1	Subbasin-1	2.20	60.1	6.18	10.68
	2	Subbasin-2	0.91	54.6	3.51	4.54
	3	Subbasin-3	5.70	61.3	8.20	20.34
B. 1978	1	Subbasin-1	2.08	72.6	6.18	10.68
		SubImp-1	0.12	98.0	3.00	3.00
	2	Subbasin-2	0.87	69.4	3.51	4.54
		SubImp-2	0.04	98.0	1.00	1.00
	3	Subbasin-3	5.70	70.1	8.20	20.34
C. 2005	1	Subbasin-1	2.08	72.4	6.18	10.68
		SubImp-1	0.12	98.0	3.00	3.00
	2	Subbasin-2	0.87	69.1	3.51	4.54
		SubImp-2	0.04	98.0	1.00	1.00
	3	Subbasin-3	5.70	68.8	8.20	20.34
D. 2009, no stormwater management	1	Subbasin-1	2.08	72.4	6.18	10.68
		SubImp-1	0.12	98.0	3.00	3.00
	2	Subbasin-2	0.74	67.7	3.51	4.54
		SubImp-2	0.04	98.0	1.00	1.00
		SubCasino-2	0.13	92.0	1.00	1.00
	3	Subbasin-3	5.70	68.8	8.20	20.34
E. 2009, casino retention	Same as D, but with SubCasino-2 deleted					
F. Future, no stormwater management	1	Subbasin-1	1.95	72.4	6.18	10.68
		SubImp-1	0.12	98.0	3.00	3.00
		SubNewDev-1	0.13	98.0	3.00	3.00
	2	Subbasin-2	0.64	66.8	3.51	4.54
		SubImp-2	0.04	98.0	1.00	1.00
		SubCasino-2	0.13	92.0	1.00	1.00
		SubNewDev-2	0.10	98.0	1.00	1.00
	3	Subbasin-3	5.70	68.8	8.20	20.34
G. Future, casino retention	Same as F, but with SubCasino-2 deleted					
H. Future, casino retention, extended detention for new development	Same as G, but with reservoir elements added (Table A2)					

Table A2: Reservoir Storage Parameters

Reservoir	Storage (acre-feet)	Discharge (cfs)
Res-1	0.0	0.0
	5.5	2.54
	11.0	3.81
Res- 2	0.0	0.0
	4.44	2.02
	8.88	3.03

Table A3: Reach Routing Parameters

Reach	Lag (minutes)
1	163
2	22

Appendix B: Dickinson Creek Hydrologic Model Calibration

Rainfall and streamflow data were collected by MDEQ HSU staff from March 11 to September 24, 2008. The intent of the monitoring was to provide data to calibrate the hydrologic model.

Water depth and temperature data, Figures B1 and B2, was recorded every 15 minutes using Solinst Levelogger Gold pressure transducers located in Dickinson Creek near Michigan Avenue and near the mouth. Ambient air pressure and temperature was recorded using a Solinst Barologger Gold pressure transducer located along Michigan Avenue near Dickinson Creek. An MDEQ rain gauge was located at the Calhoun Conservation District office, but the storm used to calibrate the model occurred when the rain gauge was plugged. Consequently, rainfall information from Michigan Automated Weather Network (MAWN) weather station at Ceresco was used.

HSU staff measured flows at low and medium stages at both Dickinson Creek locations. The measured flows were used to develop rating curves to convert stage data to flows. The higher end of both rating curves, Figures B3 and B4, are extrapolated, but checked with hydraulic modeling (HEC-RAS 4.0) at each location. The flows calculated with the rating curves and stage data are shown in Figure B5.

The Dickinson Creek hydrologic model models runoff from a singe rainfall event. For calibration, the most useful event is a single large storm event. The September 12 through 14, 2008, rainfall would appear to be a good choice, but the rainfall has six peaks, as shown in Figure B6. The model would not replicate runoff from this period unless the curve numbers could be varied over time for soil moisture conditions, and the initial abstraction and storage parameters included allowances for infiltration between rainfall peaks. For these reasons, the July 2, 2008 storm, with a single, more intense peak, Figure B7 and Table B1, is a better calibration event.

Initially, using composite ARC II curve numbers, the model poorly replicated the runoff from the July 2nd storm, as shown in Figures B8 and B9. However, curve numbers vary due to rainfall intensity and duration, total rainfall, soil moisture, cover density, stage of growth, and temperature, which are collectively called the Antecedent Runoff Condition (ARC). ARC is not the same as antecedent moisture condition (AMC). Chapter 10 of the NEH (2004) now states “No apparent relationship between antecedent precipitation and curve number exists.” ARC is divided into three classes. Classes I and III can be considered probability boundaries of the curve number variable. ARC I approximates drier conditions and ARC III wetter conditions.

The curve numbers were adjusted to ARC I conditions, and directly connected impervious areas (DCIA) were separated out for subbasins 1 and 2 with times of concentration estimated based on model optimization trials. ARC I conditions are applicable because the watershed was in the middle of the growing season, with near maximum interception, infiltration, and evapotranspiration. Adding directly connected impervious areas that generate runoff to the stream quickly is critical to approximating the observed flows. For subbasin 2, this represents imperviousness near I-94 between Michigan Avenue and Wheatfield Road. For subbasin 1, this primarily represents imperviousness near Wattles Road and I-94. The calibrated results are shown in Figures B10 and B11. The model parameters revised during the calibration process are shown in Table B2.

As a result of the calibration, all model scenarios incorporate directly connected impervious area elements, baseflow estimates, and the revised Tc for subbasin 3. However, ARC I curve numbers were used only for model calibration. For comparison purposes in this study, ARC II conditions were selected for all scenarios, as discussed in the Runoff Curve Number section of the report.

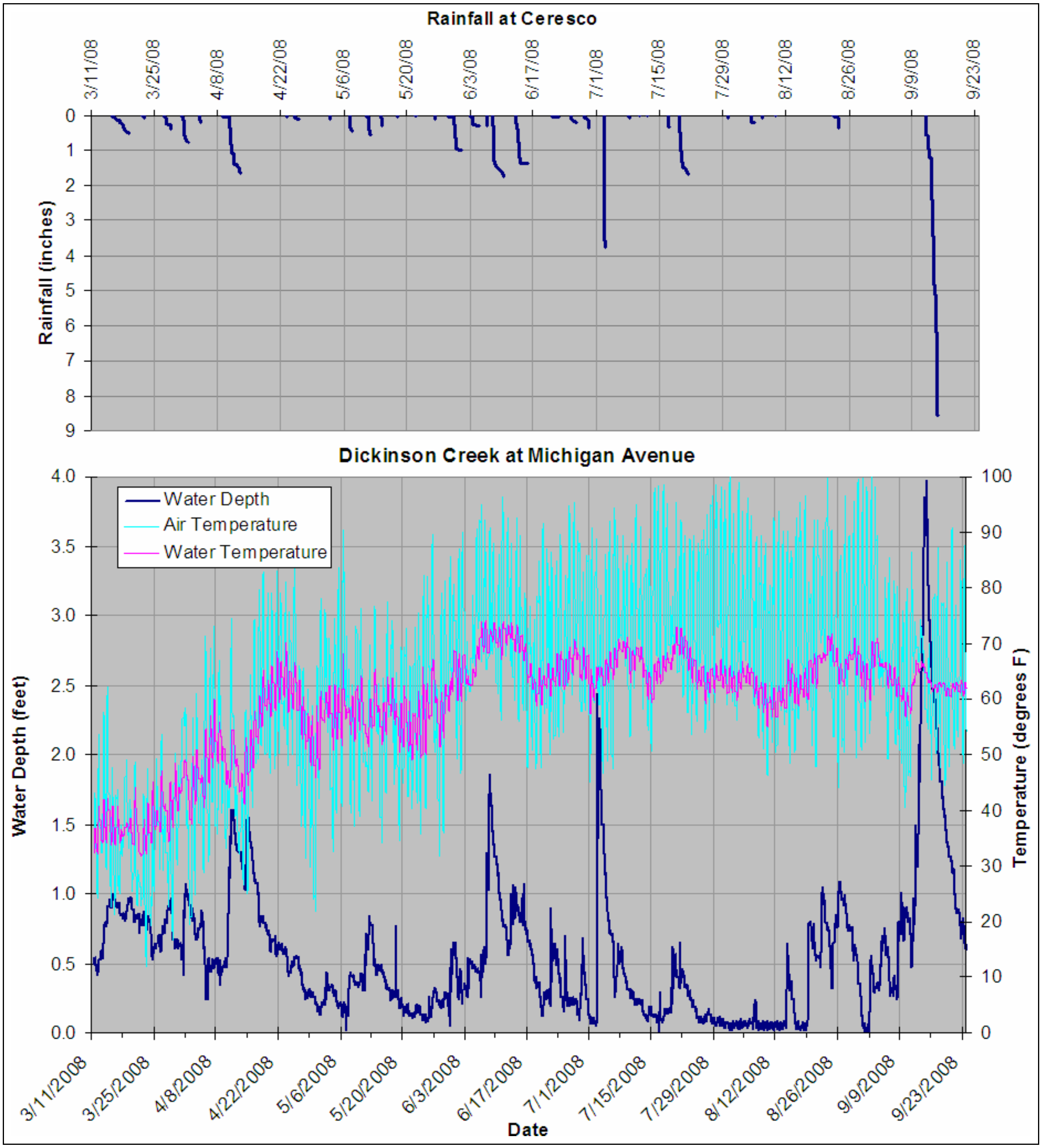

Figure B1 – Monitoring Data for Dickinson Creek at Michigan Avenue

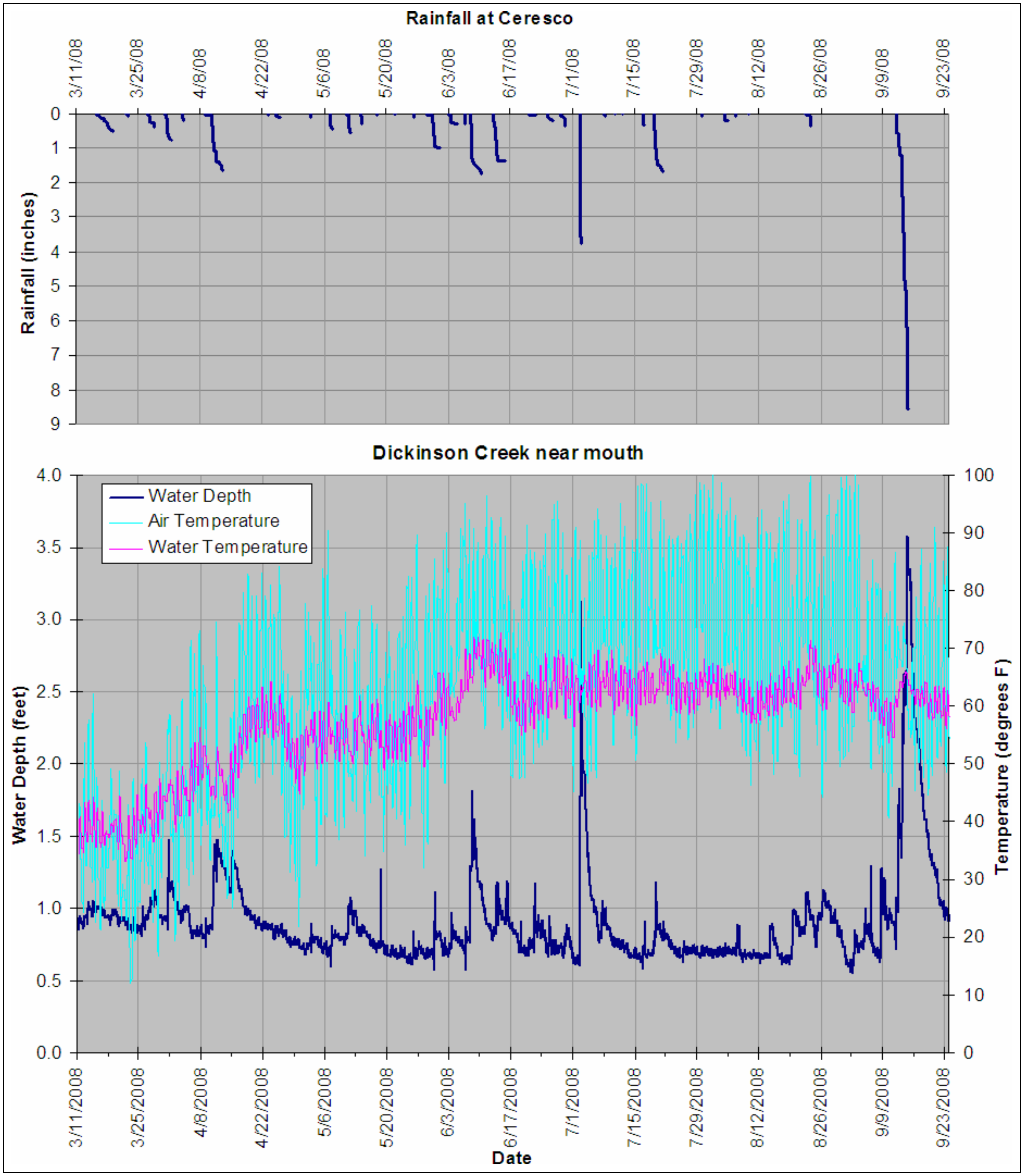

Figure B2 – Monitoring Data for Dickinson Creek near its mouth

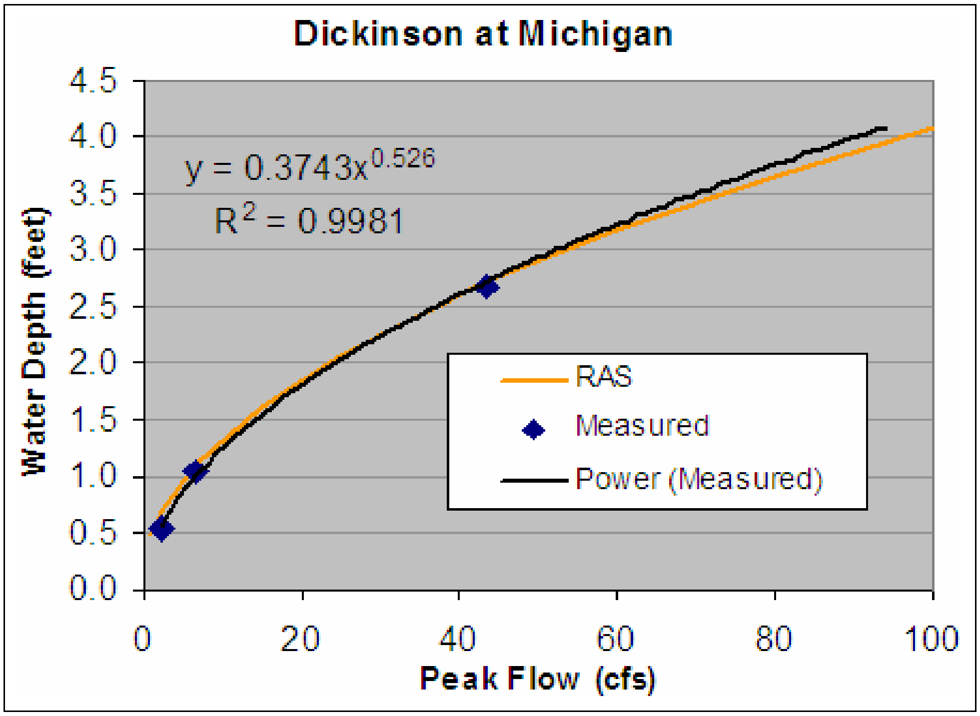

Figure B3 – Rating Curve for Dickinson Creek at Michigan Avenue

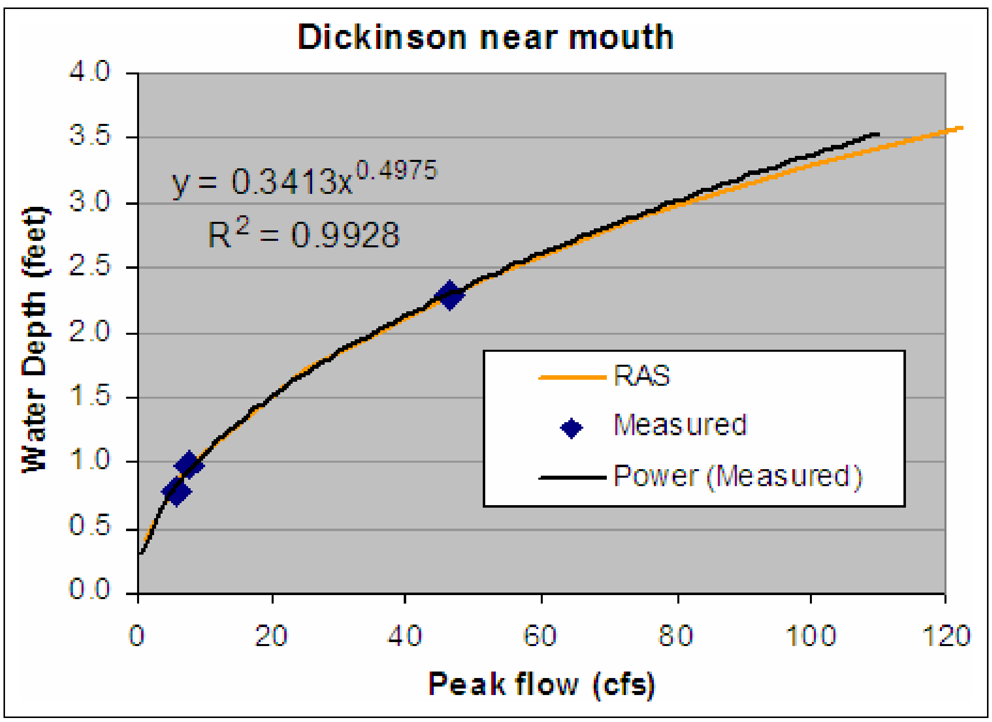

Figure B4 – Rating Curve for Dickinson Creek near mouth

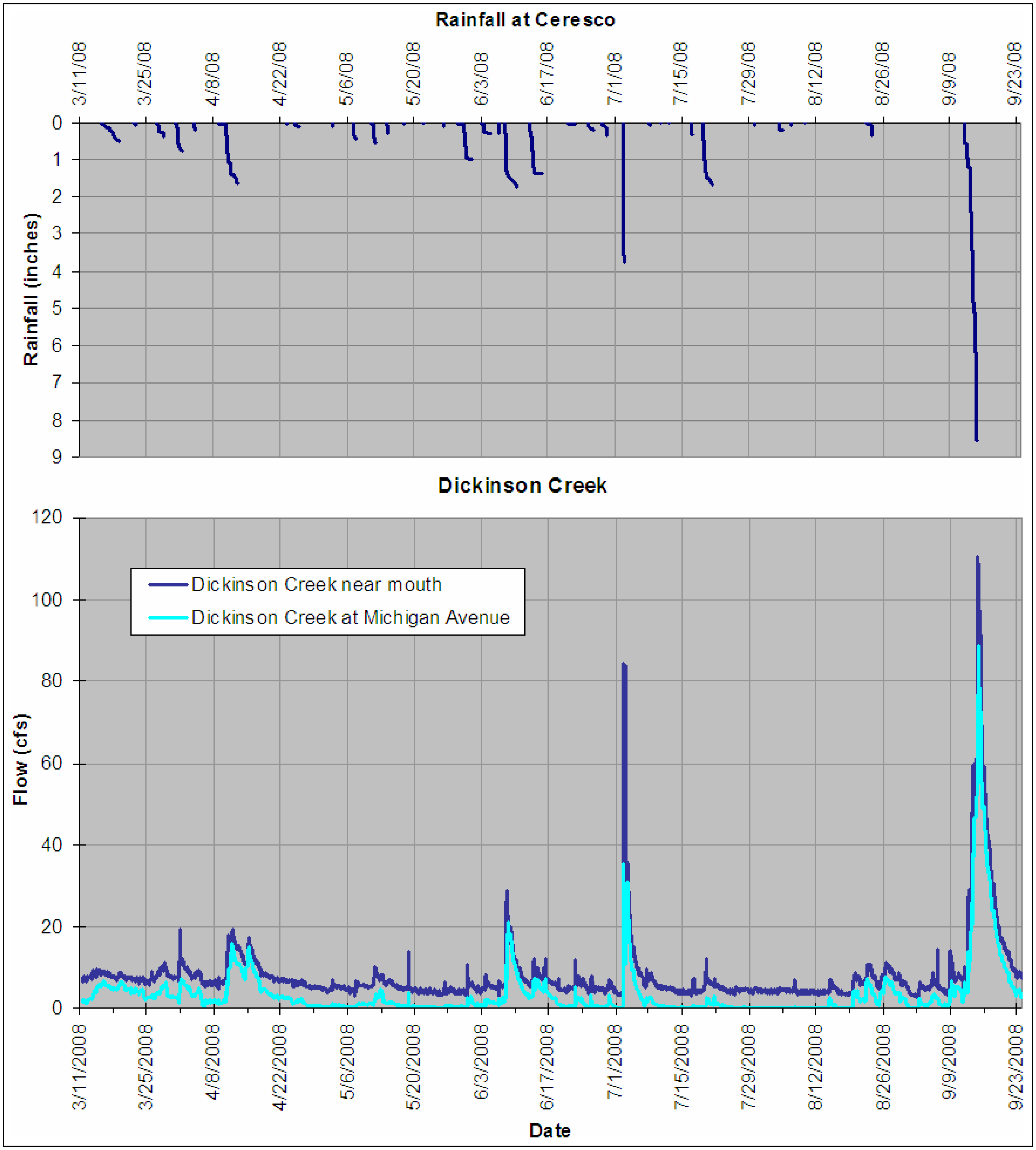

Figure B5 –Monitored Dickinson Creek Flows

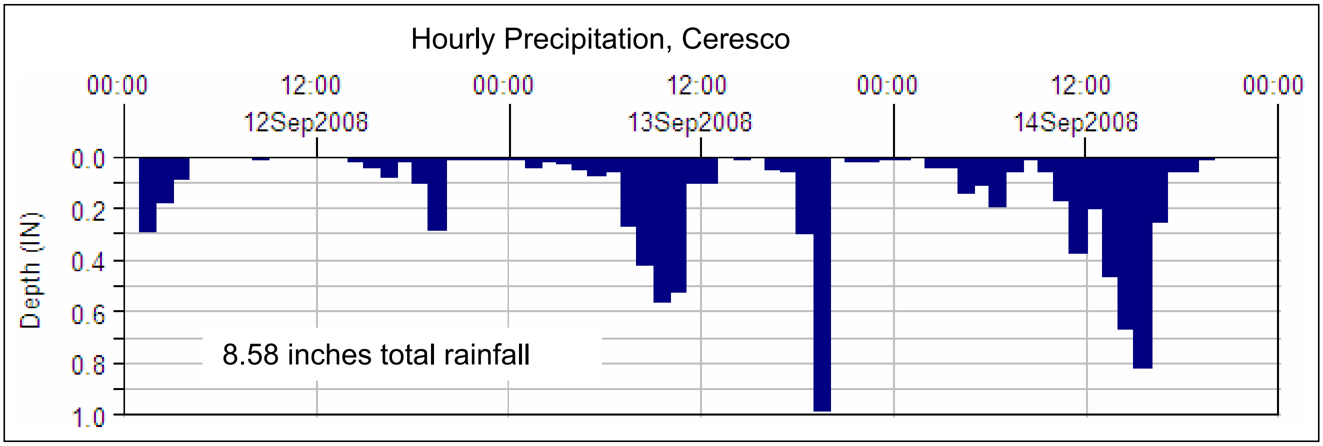

Figure B6 –September 12 through 14, 2008 Rainfall at Ceresco MAWN weather station

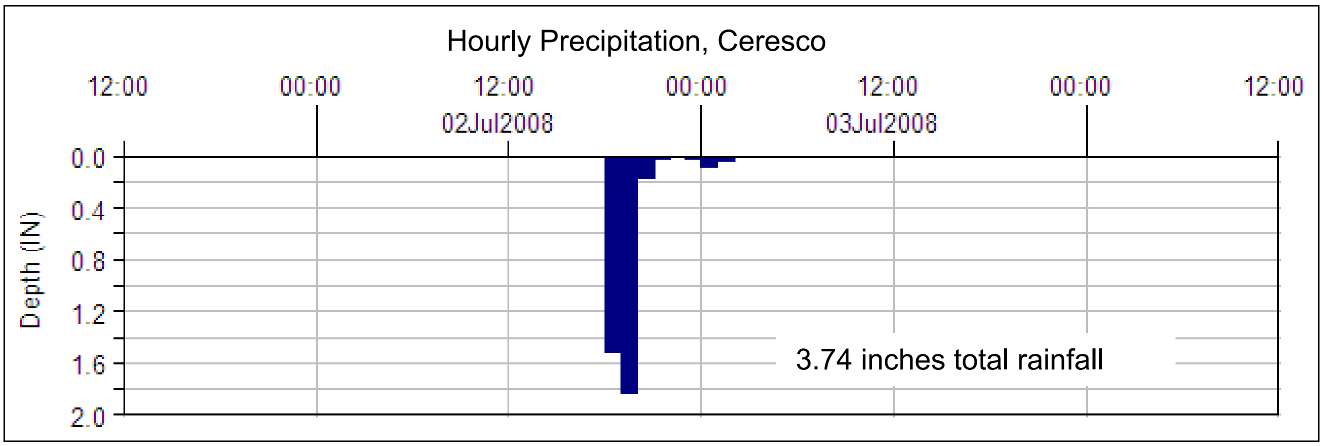

Figure B7 –July 2 and 3, 2008 Rainfall at Ceresco MAWN weather station

Table B1 – Rainfall used for Model Calibration

Date and Time	Rainfall (inches)
7/2/08 18:00	0.00
7/2/08 19:00	1.52
7/2/08 20:00	1.83
7/2/08 21:00	0.18
7/2/08 22:00	0.03
7/2/08 23:00	0.01
7/3/08 0:00	0.02
7/3/08 1:00	0.08
7/3/08 2:00	0.04
7/3/08 3:00	0.01
7/3/08 4:00	0.01
7/3/08 5:00	0.01
Total	3.74

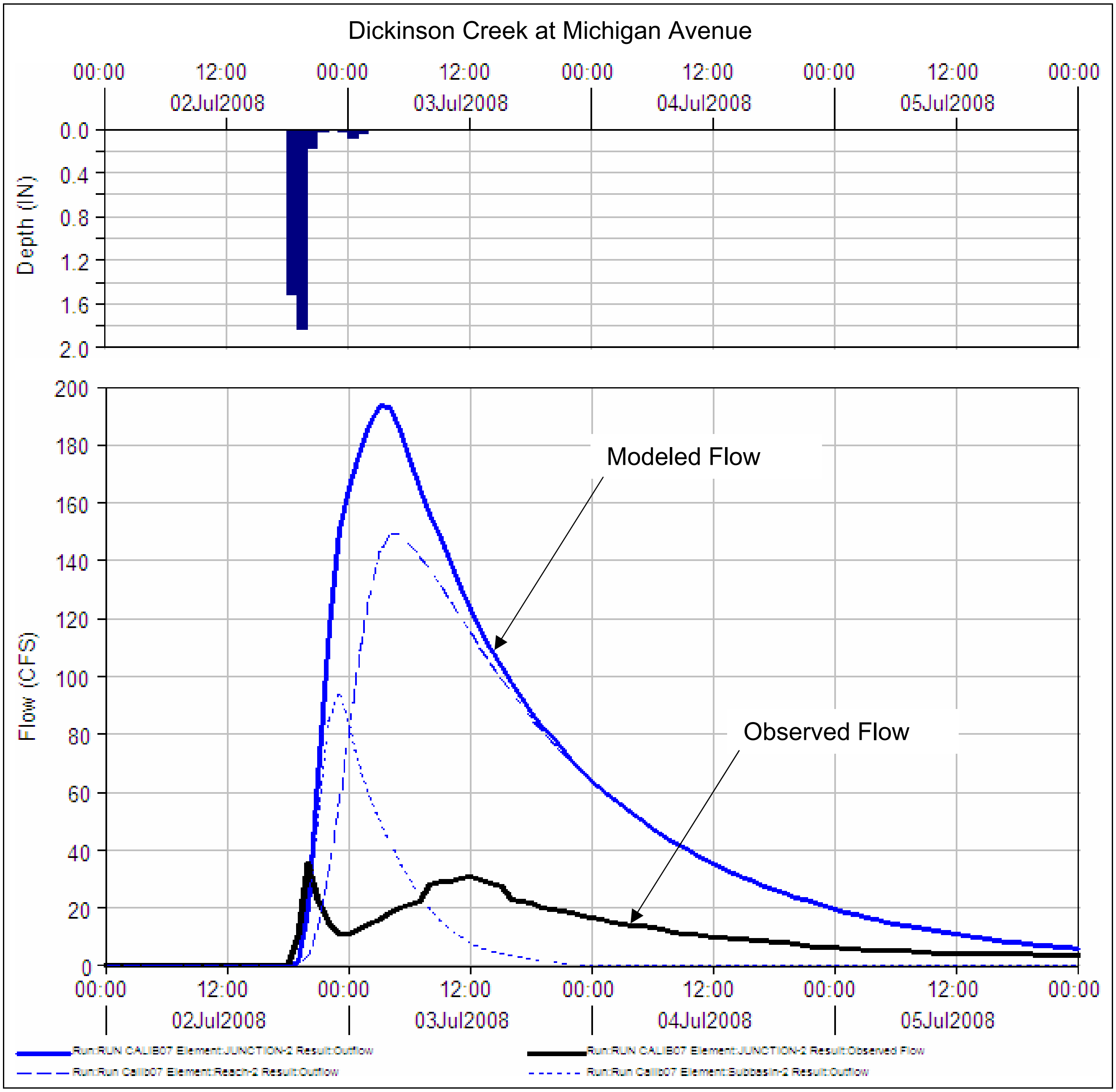

Figure B8 – Initial Model Results, Dickinson Creek at Michigan Avenue, July 2 and 3, 2008 Rainfall

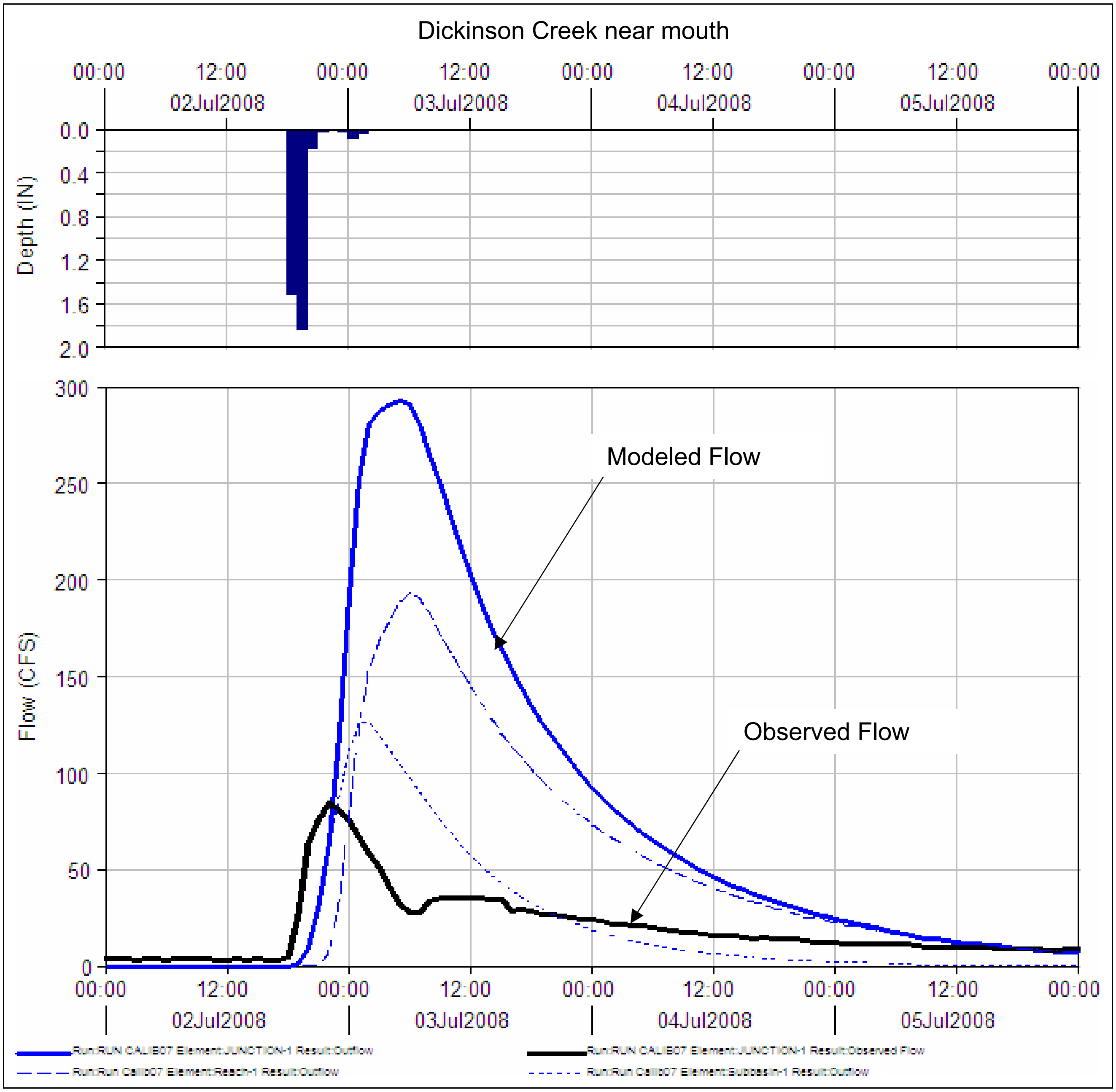

Figure B9 – Initial Model Results, Dickinson Creek near mouth, July 2 and 3, 2008 Rainfall

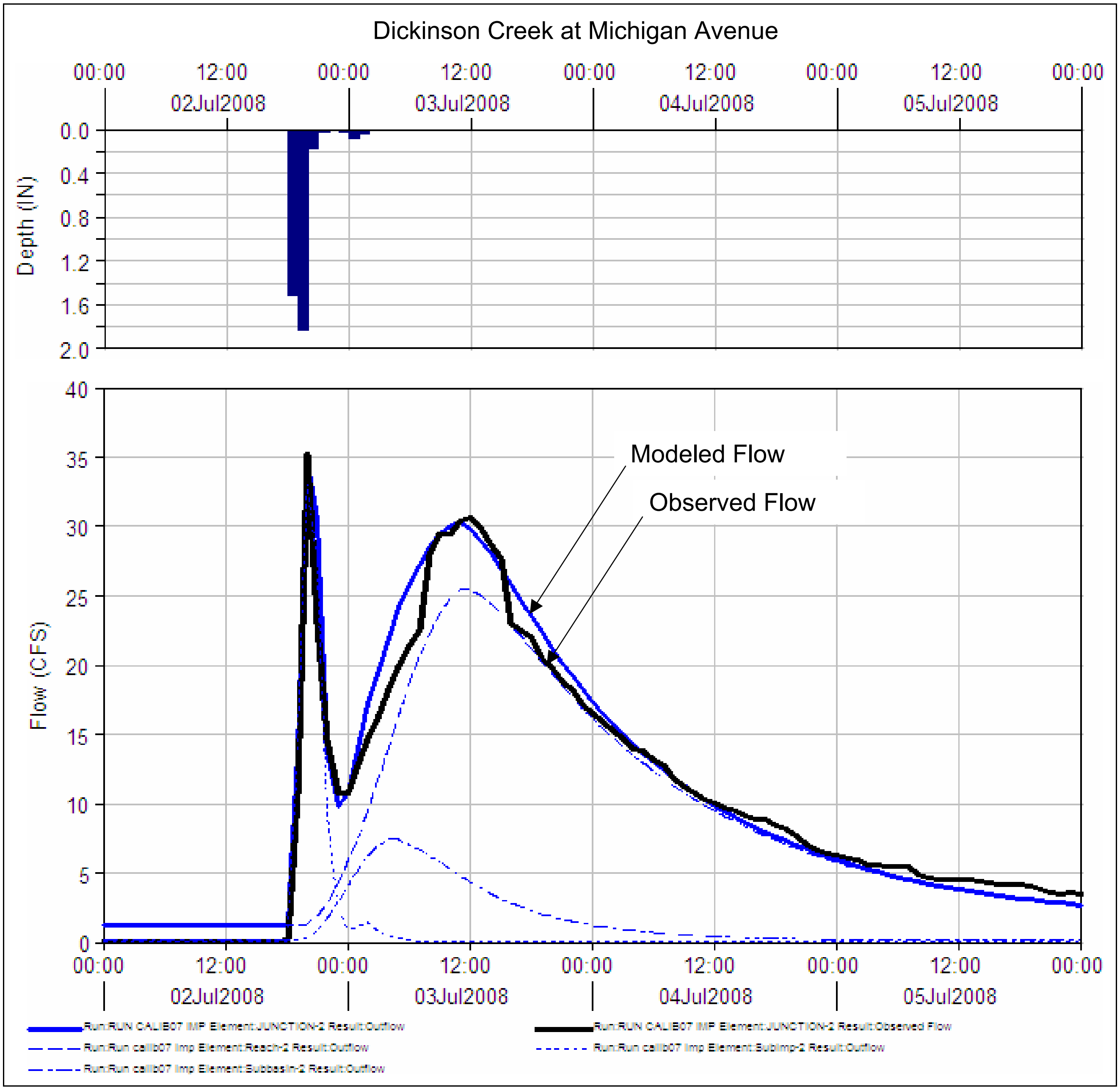

Figure B10 – Calibrated Model Results, Dickinson Creek at Michigan Avenue, July 2 and 3, 2008 Rainfall

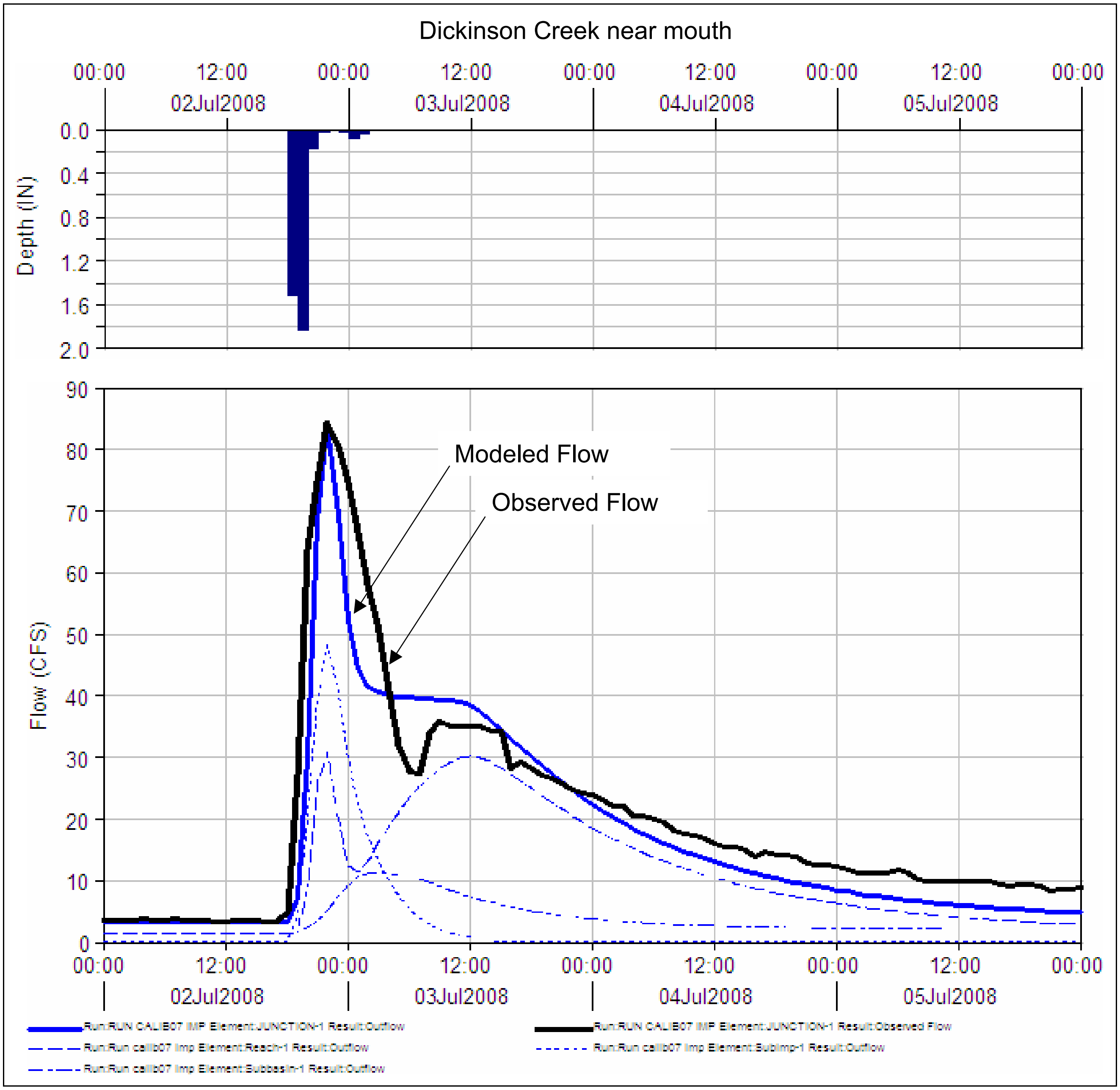

Figure B11 – Calibrated Model Results, Dickinson Creek near mouth, July 2 and 3, 2008 Rainfall

Table B2 –Model Parameters revised during calibration

Subbasin Description		Pre	Post	Explanation
1) Dickinson Creek at mouth	Area (sq. mi.)	2.20	2.08	
			0.12	DCIA element modeled separately based on calibration and watershed assessment
	CN	74.0	52.4	adjustment for separate DCIA element and adjustment from ARC II to ARC I
			98.0	DCIA element
	Tc (min.)	6.18	6.18	
			3.00	DCIA element: Tc selected based on distance to stream and calibration
	SC	10.68	10.68	
			3.00	DCIA element: SC equals Tc because no ponding for this portion of the runoff
	Baseflow (cfs)	none	2	approximates observed conditions
2) Dickinson Creek at Michigan Avenue	Area (sq. mi.)	0.91	0.87	
			0.04	DCIA element modeled separately based on calibration and watershed assessment
	CN	71.6	48.4	adjustment for separate DCIA element and adjustment from ARC II to ARC I
			98.0	DCIA element
	Tc (min.)	3.51	3.51	
			1.00	DCIA element: Tc selected based on distance to stream and calibration
	SC	4.54	4.54	
			1.00	DCIA element: SC equals Tc because no ponding for this portion of the runoff
	Baseflow (cfs)	none	0.08	approximates observed conditions, apportioned based on contributing drainage area
3) Dickinson Creek at Wheatfield Road	Area (sq. mi.)	5.70	5.70	
	CN	69.0	48.1	
	Tc (min.)	8.2	16.0	Adjusted based on calibration
	SC	20.34	20.34	
	Baseflow (cfs)	none	0.56	approximates observed conditions, apportioned based on contributing drainage area

Appendix C: Glossary

Aggrade - to fill and raise the level of a stream bed by deposition of sediment.

Alluvium - sediment deposited by flowing rivers and consisting of sands and gravels.

Bankfull discharge - that discharge that just begins to overflow into the active floodplain. The active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at recurrence interval of about 2 years or less. Most erosion, sediment transport, and bar building by deposition occur at discharges near bankfull. The effectiveness of higher flows, called over bank or flood flows, does not increase proportionally to their volume above bankfull in a stable stream, because overflow into the floodplain distributes the energy of the stream over a greater area. See also channel-forming and effective discharge.

Base Flow - the part of stream flow that is attributable to long-term discharge of groundwater to the stream. This part of stream flow is not attributable to short-term surface runoff, precipitation, or snow melt events.

Best Management Practice (BMP) - structural, vegetative, or managerial practices used to protect and improve our surface waters and groundwaters.

Channel-forming Discharge - a theoretical discharge which would result in a channel morphology close to the existing channel. See also effective and bankfull discharge.

Critical Areas - the geographic portions of the watershed contributing the majority of the pollutants and having significant impacts on the waterbody.

Critical Depth - depth of water for which specific energy is a minimum.

Curve Number - see Runoff Curve Number.

Design Flow - projected flow through a watercourse which will recur with a stated frequency. The projected flow for a given frequency is calculated using statistical analysis of peak flow data or using hydrologic analysis techniques.

Detention - practices which store stormwater for some period of time before releasing it to a surface waterbody. See also retention.

Direct Runoff Hydrograph - graph of direct runoff (rainfall minus losses) versus time.

Discharge - volume of water moving down a channel per unit time. See also channel-forming, effective, and bankfull discharge.

Drainage Divide - boundary that separates subbasin areas according to direction of runoff.

Effective Discharge - the calculated measure of channel forming discharge. This calculation requires long-term water and sediment measurements, although modeling results are sometimes substituted. See also channel-forming and bankfull discharge.

Ephemeral Stream - a stream that flows only during or immediately after periods of precipitation. See also intermittent and perennial streams.

Evapotranspiration - the combined process of evaporation and transpiration.

First Flush - the first part of a rainstorm that washes off the majority of pollutants from a site. The concept of first flush treatment applies only to a single site, even if just a few acres, because of timing of the runoff. Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet.

Flashiness - has no set definition but is associated with the rate of change of flow. Flashy streams have more rapid flow changes.

Flood Hazard Zone - area that will flood with a given probability.

Groundwater - that part of the subsurface water that is in the saturated zone.

Headwater Stream - the system of wetlands, swales, and small channels that mark the beginnings of most watersheds.

Hydraulic Analysis - an evaluation of water elevation for a given flow based on channel attributes such as slope, cross-section, and vegetation.

Hydrograph - graph of discharge versus time.

Hydrogroups - Soil groups used to estimate runoff from precipitation according to the infiltration of water when the soils receive precipitation from long-duration storms.

Hydrologic Analysis - an evaluation of the relationship between stream flow and the various components of the hydrologic cycle. The study can be as simple as determining the watershed size and average stream flow, or as complicated as developing a computer model to determine the relationship between peak flows and watershed characteristics, such as land use, soil type, slope, rainfall amounts, detention areas, and watershed size.

Hydrologic Cycle - When precipitation falls to the earth, it may:

- be intercepted by vegetation, never reaching the ground.
- infiltrate into the ground, be taken up by vegetation, and evapotranspirated back to the atmosphere.
- enter the groundwater system and eventually flow back to a surface water body.
- runoff over the ground surface, filling in depressions.
- enter directly into a surface waterbody, such as a lake, stream, or ocean.

When water evaporates from lakes, streams, and oceans and is re-introduced to the atmosphere, the hydrologic cycle starts over again.

Hydrology - the occurrence, distribution, and movement of water both on and under the earth's surface. It can be described as the study of the hydrologic cycle.

Hyetograph - graph of rainfall intensity versus time.

Impervious - a surface through which little or no water will move. Impervious areas include paved parking lots and roof tops.

Infiltration Capacity - rate at which water can enter soil with excess water on the surface.

Interflow - flow of water through the upper soil layers to a ditch, stream, etc.

Intermittent Stream - a stream that flows only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year. See also ephemeral and perennial streams.

Invert - bottom of a channel or pipe.

Knickpoint - a point of abrupt change in bed slope. If the streambed is erodible material, the knickpoint, or downcut, may migrate upstream along the channel and have undesirable effects, such as undermining bridge piers and other manmade structures.

Lag Time - time from the center of mass of the rainfall to the peak of the hydrograph.

Low Impact Development (LID) - a comprehensive design and development technique that strives to mimic pre-development hydrologic characteristics and water quality with a series of small-scale distributed structural and non-structural controls.

Losses - rainfall that does not runoff, i.e. rainfall that infiltrates into the ground or is held in ponds or on leaves, etc.

Low Flow - minimum flow through a watercourse which will recur with a stated frequency. The minimum flow for a given frequency may be based on measured data, calculated using statistical analysis of low flow data, or calculated using hydrologic analysis techniques. Projected low flows are used to evaluate the impact of discharges on water quality. They are, for example, used in the calculation of industrial discharge permit requirements.

Morphology, Fluvial - the study of the form and structure of a river, stream, or drain.

Nonpoint Source Pollution - pollutants carried in runoff characterized by multiple discharge points. Point sources emanate from a single point, generally a pipe.

Overland Flow - see Runoff.

Peak Flow - maximum flow through a watercourse which will recur with a stated frequency. The maximum flow for a given frequency may be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques. Projected peak flows are used in the design of culverts, bridges, and dam spillways.

Perched Ground Water - unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

Perennial Stream - a stream that flows continuously during both wet and dry times. See also ephemeral and intermittent streams.

Precipitation - water that falls to earth in the form of rain, snow, hail, or sleet.

Rating Curve - relationship between depth and amount of flow in a channel.

Recession Curve - portion of the hydrograph where runoff is from base flow.

Retention - practices which capture stormwater and release it slowly though infiltration into the ground. See also detention.

Riparian - pertaining to the bank of a river, pond, or small lake.

Runoff - flow of water across the land surface as surface runoff or interflow. The volume is equal to the total rainfall minus losses.

Runoff Coefficient - ratio of runoff to precipitation.

Runoff Curve Number - parameter developed by the Natural Resources Conservation Service (NRCS) that accounts for soil type and land use.

Saturated Zone - (1) those parts of the earth's crust in which all voids are filled with water under pressure greater than atmospheric; (2) that part of the earth's crust beneath the regional water table in which all voids, large and small, are filled with water under pressure greater than atmospheric; (3) that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Scarp - the sloped bank of a stream channel.

Sediment - soil fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice.

Sinuosity - the ratio of stream length between two points divided by the valley length between the same two points.

Simulation Model - model describing the reaction of a watershed to a storm using numerous equations.

Soil - unconsolidated earthy materials which are capable of supporting plants. The lower limit is normally the lower limit of biological activity, which generally coincides with the common rooting of native perennial plants.

Soil Moisture Storage - volume of water held in the soil.

Storage Delay Constant - parameter that accounts for lagging of the peak flow through a channel segment.

Storage-Discharge Relation - values that relate storage in the system to outflow from the system.

Stream Corridor - generally consists of the stream channel, floodplain, and transitional upland fringe.

Subbasins - hydrologic divisions of a watershed that are relatively homogenous.

Synthetic Design Storm - rainfall hyetograph obtained through statistical means.

Synthetic Unit Hydrograph - unit hydrograph for ungaged basins based on theoretical or empirical methods

Thalweg - the "channel within the channel" that carries water during low-flow conditions.

Time of Concentration - the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the design point.

Transpiration - conversion of liquid water to water vapor through plant tissue.

Tributary - a river or stream that flows into a larger river or stream.

Unit Hydrograph - graph of runoff versus time produced by a unit rainfall over a given duration.

Unsaturated Zone - the zone between the land surface and the water table which may include the capillary fringe. Water in this zone is generally under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Vadose Zone - see Unsaturated Zone.

Watershed - area of land that drains to a single outlet and is separated from other watersheds by a divide.

Watershed Delineation - determination of watershed boundaries. These boundaries are determined by reviewing USGS quadrangle maps. Surface runoff from precipitation falling anywhere within these boundaries will flow to the waterbody.

Water Surface Profile - plot of the depth of water in a channel along the channel's length.

Water Table - the surface of a groundwater body at which the water pressure equals atmospheric pressure. Earth material below the groundwater table is saturated with water.

Yield (Flood Flow) - peak flow divided by drainage area

Appendix D: Abbreviations

AMC	Antecedent Moisture Condition
ARC	Antecedent Runoff Condition
BEHI	Bank Erosion Hazard Index
BMP	Best Management Practice
cfs	cubic feet per second
CN	Runoff Curve Number
DCIA	Directly Connected Impervious Area
EPA	United States Environmental Protection Agency
GIS	Geographic Information Systems
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HSU	MDEQ's Hydrologic Studies Unit
ICM	Impervious Cover Model
IPD	Incipient Particle Diameter
LID	Low Impact Development
LWMD	MDEQ's Land and Water Management Division
MDEQ	Michigan Department of Environmental Quality
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
P	Precipitation
S	Potential Maximum Retention
SC	Storage Coefficient
USGS	United States Geological Survey
WARSSS	Watershed Assessment of River Stability and Sediment Supply

Appendix E: Work Index Equation Derivation

Bank shear stress can be computed as $\tau = \gamma d s_o$ where γ is the unit weight of water, d is the depth of flow, and s_o is the stream bed slope. Streambank erosion begins when the shear stress exceeds some critical value, τ_c, often referred to as the critical shear stress for bed mobility. The erosive power for per unit area of stream bank is $P = (\tau - \tau_c) V$, where V is the stream velocity. The erosive work is the erosive power integrated over the duration of the flood event or

$$W = \int_{Flood} P dt = \int_{Flood} (\gamma d s_o - \tau_c)^e V dt.$$

In this equation, e is an exponent between 1 and 2.5 (MacRae 1992, 1996). An alternative is to write the equation in terms of the critical depth for bed mobility, d_c. The critical shear stress can then be computed as $\tau_c = \gamma d_c s_o$. When this is substituted into the above equation for erosive work, the following results:

$$W = \int_{Flood} \gamma s_o (d - d_c)^e V dt.$$

Assuming the unit weight and channel slope are constant:

$$W' = \int_{Flood} (d - d_c)^e V dt.$$

Appendix F: Modified Tractive Force Equation Derivation

The modified tractive force equation is best used as a screening tool to estimate the particle size on the channel bottom that will likely be moved by the water flowing above it.

$$d_p = D_w\, S$$

where

d_p is particle diameter mobilized in mm
D_w is the channel depth in cm
S is channel slope in m/m or ft/ft

Although it has inconsistent units, its units were actually selected to provide an unstated conversion factor of one. It is derived from two fundamental shear stress equations as described below. The stress equations are from different scales of analysis: one is a point analysis on a sediment particle, the other a channel scale analysis on the channel's bed. For this derivation, the point analysis is assumed typical of the entire channel, recognizing that in real streams, stresses at points across a channel will vary with local conditions.

Shear stress on the bed material caused by the flowing water can be calculated using the boundary shear stress equation, below, for uniform flow in a straight, open channel. The boundary shear stress equation for meanders is described in the box to the right for reference, but is not used in this derivation.

$$\tau_o = \gamma_w RS$$

where,

τ_o is boundary shear stress in N/m^2
γ_w is the density of water in N/m^3
R is hydraulic radius of the channel in m
S is channel slope in m/m or ft/ft

> If the channel curves, the shear stress will be higher on the outside of the bend than the inside. The equation becomes:
>
> $$\tau_o = \gamma_w RS(R_c/B)$$
>
> where
> R_c is radius of curvature in m or feet
> B is bottom width in consistent units
>
> Typical values of R_c/B are
> Straight reach 1.0
> Mild meanders 1.1 to 1.4
> Looping meanders 1.5 to 1.8
> Sharp turns 1.9 to 2.1

Incipient mobilization, or entrainment, of sediment particles can be calculated with the Shields critical shear equation:

$$\tau_{cr} = \Theta g(\rho_p - \rho_w)d_p$$

where,

τ_{cr} is boundary shear stress at the threshold of entrainment in N/m^2
Θ is a dimensionless shear parameter
g is the acceleration due to gravity m/sec^2
ρ_p is the density of the sediment particle in kg/m^3
$\rho\omega$ is the density of water in kg/m^3
d_p is particle diameter in m

Setting $\tau_o = \tau_{cr}$ results in:

$$\Theta g(\rho_p - \rho_w)d_p = \gamma_w RS$$

Assuming γ_W = 9,800 N/m^3, g = 9.8 m/sec^2, ρ_p = 2,650 kg/m^3 and ρ_W = 1,000 kg/m^3, the equation becomes:

$$(\Theta)(9.8 \text{ m/sec}^2)(1650 \text{ kg/m}^3)(d_p \text{ m}) = (9800 \text{ kg/m}^2\text{sec}^2)(R \text{ m})(S)$$

For hydraulically rough channels, Θ is most often estimated as 0.06, but varies with hydraulic roughness, Table F1. For hydraulically smooth channels, Θ is much higher: 0.8-3.0.

Table F1

Channel	Θ
Normal beds: "settled" bed with uniform or random arrangement of grain sizes	0.035-0.065
Loose beds: quick sands and gravels with large water-filled voids	0.01-0.035
Packed beds: smaller material filling voids between larger components	0.065-0.1
Highly embedded with fines	>0.1

(from Carson & Griffiths 1987)

Assuming Θ = 0.06, the equation simplifies to:

$$(9.8 \text{ m/sec}^2)(100 \text{ kg/m}^3)(d_p \text{ m}) = (9800 \text{ kg/m}^2\text{sec}^2)(R \text{ m})(S)$$

$$(980 \text{ kg/m}^2\text{sec}^2)(d_p \text{ m}) = (9800 \text{ kg/m}^2\text{sec}^2)(R \text{ m})(S)$$

$$d_p \text{ m} = 10 \ (R \text{ m}) \ (S)$$

In wide channels, R can be approximated by the water depth, D_w. In narrow, deep channels, R will be less than D_w. Figure D1 illustrates the error for a rectangular channel.

$$d_p \text{ m} = 10 \ (D_w \text{ m}) \ (S)$$

when d_p is expressed in cm and D_w in mm, the equation becomes:

$$d_p \text{ mm} = (D_w \text{ cm}) \ (S)$$

In summary, this simplification applies to uniform flow in a straight channel with hydraulic roughness conforming to the assumption that the dimensionless shear parameter is approximately 0.06. Bends, local turbulence, and smoother channels can all increase the particle size mobilized. Rosgen, 2006 has also noted that "in heterogeneous bed materials, larger particles are entrained at shear stress values much lower than indicated" by the Shields critical shear equation. This is detailed on pages 2-8 through 2-10 and 5-139 of "Watershed Assessment of River Stability and Sediment Supply (WARSSS)."

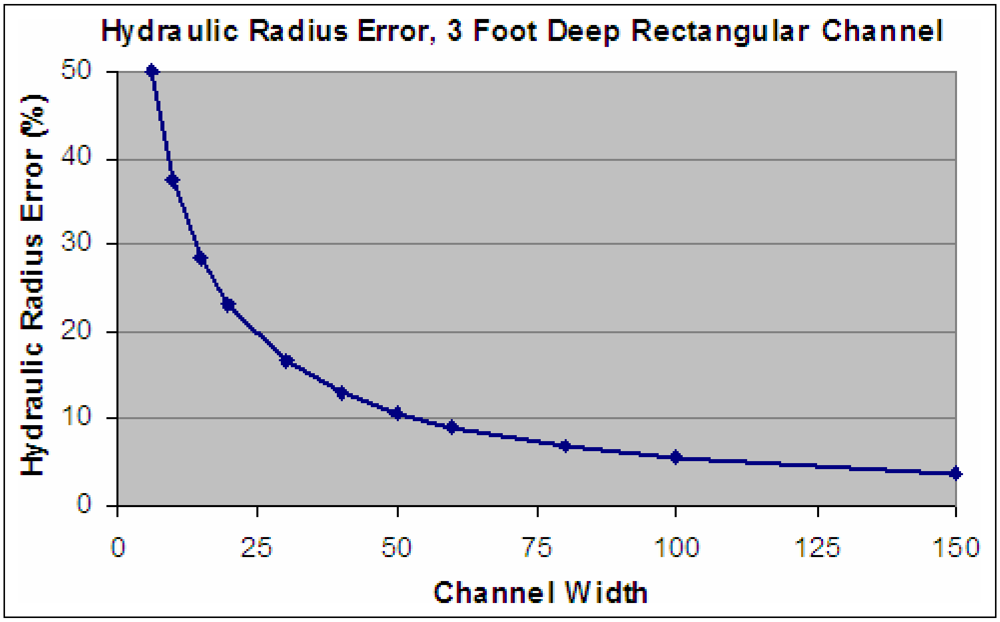

Figure D1 – Percent error incurred by substituting water depth for hydraulic radius in a rectangular channel